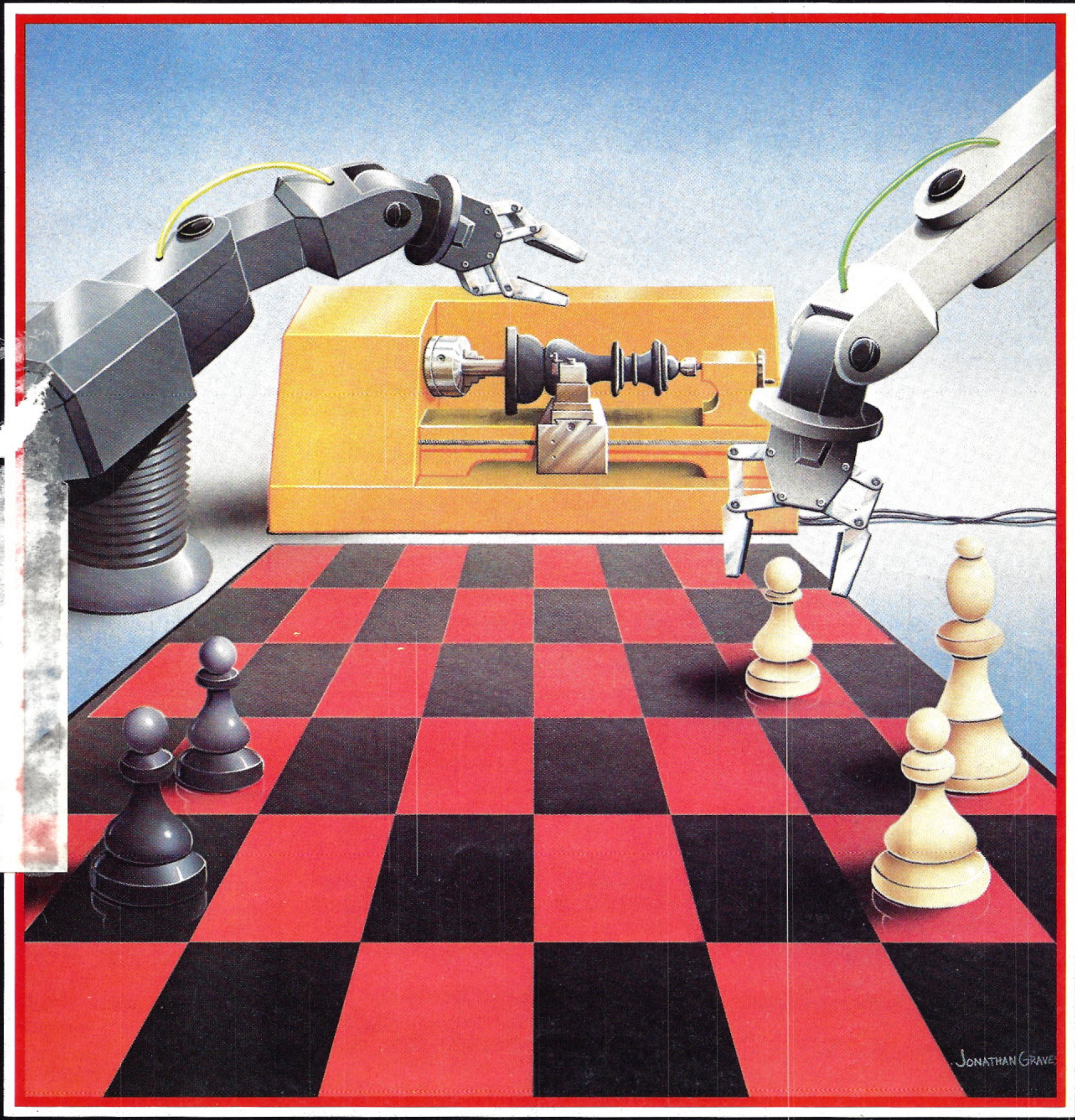
JUNE 1984 VOL. 6 NO. 6 $3.00 USA/$3.50 CANADA

THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS™ AGE



Super assemblers plus the world's largest selection of cross assemblers!

Z-80
Macroassembler $49.50
Power for larger programs! This 2500AD macroassembler includes:
- Zilog Z-80 Macroassembler (with the same powerful features as all our assemblers)
- powerful linker that will link up to 128 files
- Intel 8080 to Zilog Z-80 Source Code Converter (to convert all your Intel source to Zilog Syntax in one simple step)
- COM to Hex Converter (to convert your object files to Hex for PROM creation, etc.)
- 52 pages User Manual

8086/88 Assembler with Translator $99.50
Available for MSDOS, PCDOS, or CPM/86! This fully relocatable macro-assembler will asemble and link code for MSDOS (PCDOS) AND CPM/86 on either a CPM/86 or MSDOS machine. This package also includes:
- An 8080 to 8086 source code translator (no limit on program size to translate)
- A Z-80 to 8086 translator
- 64 page user manual
- 4 linkers included:
  - –MSDOS produces .EXE file
  - –CPM/86 produces .CMD file
  - –Pure object code generation
  - –Object code and address information only

Linker features:
- Links up to 128 files
- Submit mode invocation
- Code, Data Stack and extra segments
- Handles complex overlays
- Written in assembly language for fast assemblies.
- MICROSOFT .REL format option

Z-8000 Cross Development Package $199.50
Instant Z-8000 Software! This package allows development and conversion of software for the Z8001, 8002, 8003 and 8004 based machines on a Z-80, Z-8000 or 8086 machine. This powerful package includes:
- a Z-80/8080 to Z-8000 Assembly Language Source Code Translator
- Z-8000 Macro Cross Assembler and Linker

The Translators provide Z-8000 source code from Intel 8080 or Zilog Z-80 source code. The Z-8000 source code used by these packages are the unique 2500AD syntax using Zilog mnemonics, designed to make the transition from Z-80 code writing to Z-8000 easy.

All 2500 AD Assemblers and Cross Assemblers support the following features:

Relocatable Code — the packages include a versatile Linker that will link up to 128 files together, or just be used for external reference resolution. Supports separate Code and Data space. The Linker allows Submit Mode or Command Invocation.

Large File Handling Capacity—the Assembler will process files as large as the disk storage device. All buffers including the symbol table buffer overflow to disk.

Powerful Macro Section—handles string comparisons during parameter substitutions. Recursion and nesting limited only by the amount of disk storage available.

Conditional Assembly—allows up to 248 levels of nesting.

Assembly Time Calculator—will perform calculations with up to 16 pending operands, using 16 or 32 Bit arithmetic (32 Bit only for 16 Bit products). The algebraic hierarchy may be changed through the use of parentheses.

Include files supported—

Listing Control—allows listing of sections on the program with convenient assembly error detection overrides, along with assembly run time commands that may be used to dynamically change the listing mode during assembly.

Hex File Converter, included—for those who have special requirements, and need to generate object code in this format.

Cross reference table generated—

Plain English Error Messages—

System requirements for all programs: Z-80 CP/M 2.2 System with 54k TPA and at least a 96 column printer is recommended. Or 8086/88 256k CP/M-86 or MSDOS (PCDOS).

Cross Assembler Special Features

Z-8—512 User defined registers names, standard Zilog *and* Z-80 style syntax support.
8748—standard Intel *and* Z-80 style syntax supported.
8051—512 User defined register or addressable bit names.
6800 Family—absolute or relocatable modes, all addressing modes supported, Motorola syntax compatible.
6502—Standard syntax or Z-80 type syntax supported, all addressing modes supported.

8086 and Z-8000 XASM includes Source Code Translators

	Z-80 CP/M®	ZILOG SYSTEM 8000 UNIX	IBM P.C. 8086/88 MSDOS	IBM P.C. 8086/88 CP/M 86	OLIVETTI M-20 PCOS
8086/88 ASM			$ 99.50	$ 99.50	
8086/88 XASM	$199.50	$750.00			$199.50
16000(all) XASM *new*	199.50	750.00	199.50	199.50	199.50
68000 XASM *new*	199.50	750.00	199.50	199.50	199.50
Z-8000™ ASM		750.00			299.50
Z-8000 XASM	199.50		199.50	199.50	
Z-80 ASM	49.50				
Z-80 XASM		500.00	99.50	99.50	99.50
Z-8 XASM	99.50	500.00	99.50	99.50	99.50
6301(CMOS) *new*	99.50	500.00	99.50	99.50	99.50
6500 XASM	99.50	500.00	99.50	99.50	99.50
6502 XASM	99.50	500.00	99.50	99.50	99.50
65CO2(CMOS) XASM *new*	99.50	500.00	99.50	99.50	99.50
6800,2,8 XASM	99.50	500.00	99.50	99.50	99.50
6801,03 XASM	99.50	500.00	99.50	99.50	99.50
6805 XASM	99.50	500.00	99.50	99.50	99.50
6809 XASM	99.50	500.00	99.50	99.50	99.50
8748 XASM	99.50	500.00	99.50	99.50	99.50
8051 XASM	99.50	500.00	99.50	99.50	99.50
8080 XASM	99.50	500.00	99.50	99.50	99.50
8085 XASM *new*	99.50	500.00	99.50	99.50	99.50
1802 XASM *new*	99.50	500.00	99.50	99.50	99.50
F8/3870 XASM *new*	99.50	500.00	99.50	99.50	99.50
COPS400 XASM *new*	99.50	500.00	99.50	99.50	99.50
NEC7500 XASM *new*	99.50	500.00	99.50	99.50	99.50
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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS AGE™

JUNE 1984 VOL. 6 NO. 6

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: Coupling personal computers with small-scale precision CNC tools opens the possibility of tabletop manufacturing systems. This month's cover by Jonathan Graves displays a fanciful production system for chess pieces.

BPA Membership (SMA Division) Applied for, August 1983

LOGO, THE NEGLECTED LANGUAGE

When asked to name languages appropriate for artificial intelligence, expert system, and robot control experimentation, most people will choose languages such as Lisp (and all its variants), Sail, Actor, Flavors, etc. One language which is rarely mentioned is Logo.

Logo . . . isn't that for kids? Most people associate Logo with graphical turtles and school children. Although it was designed to provide a simple introduction to the world of computing, Logo has powerful computational constructs seated beneath its turtle veneer.

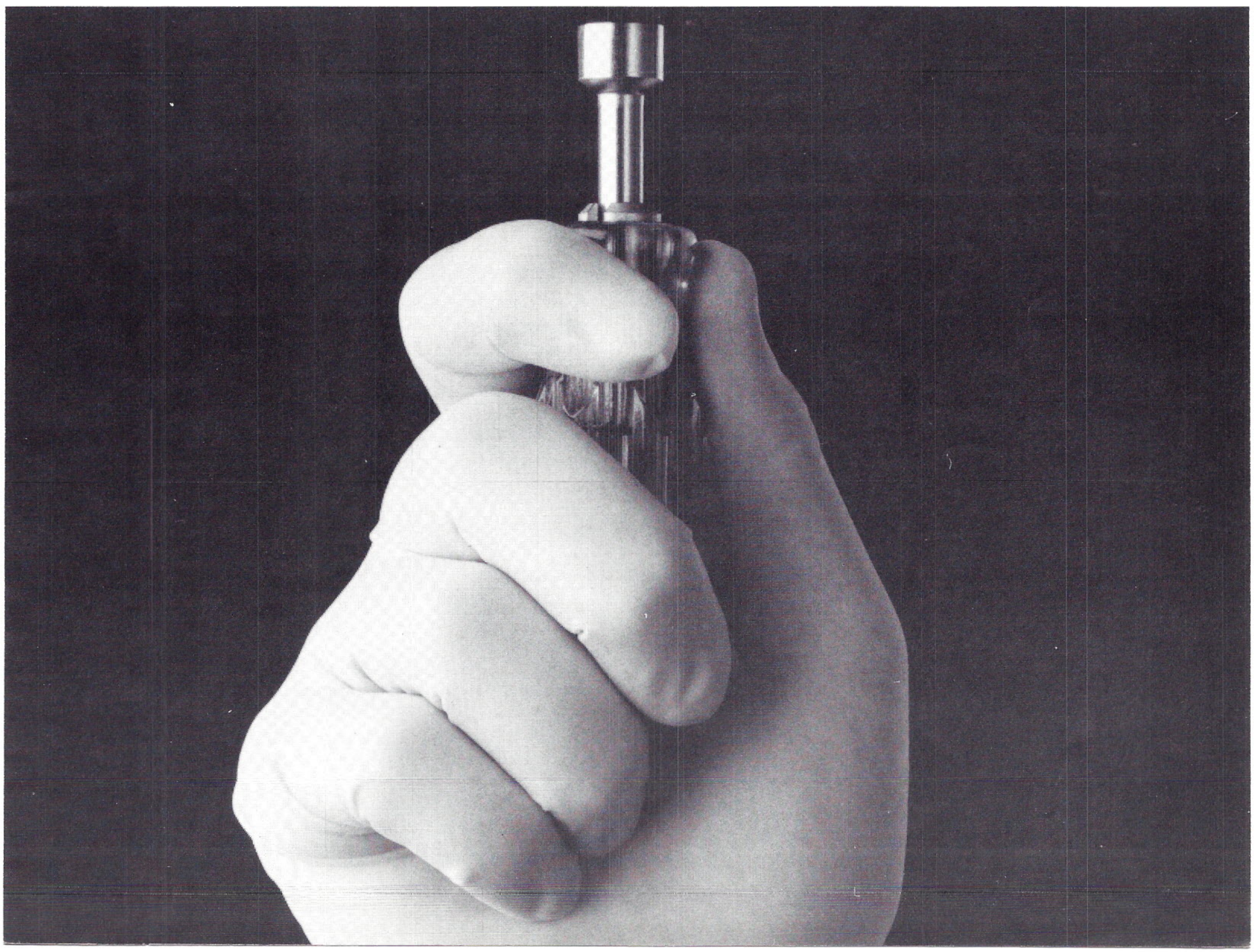
Logo is basically a friendly implementation of Lisp. Like Lisp, its strength comes from the ability to easily manipulate lists. It provides a level of data abstraction not found in languages such as Pascal and Ada. Variables can be assigned *properties* which can be compared to the properties of other variables. Logo can write its own program, execute it, examine the results, modify the program, and re-execute it. This ability to modify models as more information is received is of primary importance to artificial intelligence programs.

The differences between Logo and Lisp are mostly superficial. Logo does not require the high density of parentheses that is so indicative of Lisp. Many of the Lisp function names have been changed. CAR is now simply called FIRST and CDR is REST. Changes such as these keep people from having to delve through obtuse terms just to attain the power of the language.

At the recent International Personal Robot Congress, I spoke with several people who also believe that Logo needs to be considered a serious design language. The subject of building Logo into a personal/experimental robot leads to conclusions on several different levels.

Adding Logo to a personal robot provides an immediate communication interface through turtle commands, which would allow children and nontechnical adults to program a robot to march around the house. Turtle commands would

Continued on page 41



Calendar

JUNE

4–7 June. Robots 8. Cobo Hall, Detroit, MI. Contact: Jeff Burnstein, Robotics Institute of America, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-0778.

The theme for this year's annual Robots show is *Merging Technologies*. More than 20,000 specialists, industrialists, manufacturing engineers, and executives are expected to attend the four-day event. The conference features more than 80 leading experts explaining new aspects of robot implementation, applications, and research. The exposition will occupy the entire main level and additional exhibit space at Cobo Hall.

1984 Kansas Computer Exhibition & Robotics Conference. Century II Convention Center, Wichita, KS. Contact: Ron Holmes, Wichita Group, Inc., PO Box 47186, Wichita, KS 67201, telephone (316) 269-1022. A Robotics Conference will be included in the 1984 Kansas Computer Exhibition.

The conference will feature speakers, demonstrations, audiovisual presentations, and exhibits, with an emphasis on personal, aerospace, and agricultural applications of robotics. Representatives of robot manufacturers, university-sponsored robotics programs, and the robotics press have been invited to speak. Approximately 10,000 people from across Kansas and adjacent states are expected to attend.

19–21 June. 3rd Canadian CAD/CAM & Robotics Exposition and Conference. Toronto International Centre of Commerce. Contact: Hugh F. Macgregor & Associates, 662 Queen Street West, Toronto, Ontario M6J 1E5 CANADA, telephone (416) 363-2201.

This exposition is the major Canadian marketplace for advanced manufacturing systems. Conference topics include: Robotics Justification for Management, CAD/CAM, Robotics Education, Robotics Socio-Economic Considerations, Robotics Engineering, and Robotics Applications.

25–29 June. Computer Vision and Image Processing—8409. University of Michigan. Contact: The University of Michigan, College of Engineering, Engineering Summer Conferences, Chrysler Center, North Campus, Ann Arbor, MI 48109, telephone (313) 764-8490.

With the advent of high-speed computers, processing and extracting information from images has become an important technology. This course presents techniques for processing images and recovering useful information with emphasis on solving problems having a variety of applications.

JULY

9–12 July. 1984 National Computer Conference. Las Vegas Convention Center, Las Vegas, NV. Contact: Trudi Riley, AFIPS, 1899 Preston White Drive, Reston, VA 22091, telephone (703) 620-8952.

Enhancing Creativity is the theme of the twelfth annual NCC. The conference will focus on how the widespread availability of computing resources is altering the office, factory, and home.

23–27 July. SIGGRAPH '84. Minneapolis, MN. Contact: SIGGRAPH Conference Office, 111 East Wacker Drive, Chicago, IL 60601, telephone (312) 644-6610.

This year's SIGGRAPH Conference attendees will be treated to a vast array of technical and exhibit offerings. The program includes up to 30 one- or two-day courses, panels on topical computer graphics issues,

a larger number of exhibits, a design arts show, and the premiere of the first totally computer-generated Omnimax film.

30 July–3 August. Robot Manipulators, Computer Vision, and Automated Assembly. MIT, Boston, MA. Contact: Director of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139.

A short course given at MIT to prepare participants for the sophisticated methods soon to be employed in advanced automation. The emphasis is on developing strategies for the solution of problems in sensing, spatial reasoning, and manipulation. The use of existing industrial robots and binary vision systems is also covered.

30 July–3 August. Robotics: Concepts, Theory, and Applications. University of Michigan. Contact: The University of Michigan, College of Engineering, Engineering Summer Conferences, Chrysler Center, North Campus, Ann Arbor, MI 48109, telephone (313) 764-8490.

Course covers concepts and mathematics of computer-based robots. Topics include kinematics, dynamics and control, robotic vision, integration of sensor systems, robotic languages, economic justification, and applications. Laboratory sessions using PUMA robot arms illustrate the concepts presented in the lectures.

AUGUST

1–3 August. The Computer: Extension of the Human Mind. Eugene, Oregon. Contact: Summer Conference Office, College of Education, University of Oregon, Eugene, Oregon 97403.

This conference, the third annual computer and instructional technologies conference to be sponsored by the Center for Advanced Technology in Education, will focus on the needs of the individual who has become responsible for school and district-level use of computers and other emerging instructional technologies. Both general and special interest group sessions will be supplemented with an extensive vendor hall and film/video theater related to computer technology in education. Pre- and post-conference workshops will be conducted on the educational uses of computers.

5–8 August. Lisp and Functional Programming. University of Texas at Austin. Contact: Robert S. Boyer, University of Texas at Austin, Institute for Computing Science, 2100 Main Building, Austin, TX 78712, telephone (512) 471-1901.

This is the third in a series of biennial conferences on the Lisp language and issues related to applicative languages. Areas of interest include implementation problems; programming environments; large implementations; support tools; architectures; microcode and hardware implementations; significant language extensions; lazy evaluation; functional programming; logic programming; combinators; FP; APL; Prolog; and other languages.

20–24 August. National Conference and Exhibition on Robotics—1984. Melbourne, Australia. Contact: The Conference Manager, Institution of Engineers-Australia, 11 National Circuit, BARTON, A.C.T. 2600, AUSTRALIA, telephone (062) 73-633.

This conference promises to be the most important Australian robotic event held to date. It will have a strong application and education emphasis. Leading Australian robot users, developers, and researchers will present their experience and views on this important high-technology area.

SEPTEMBER

10–13 September. 10th Annual Advanced Control Conference. Fowler Hall, Stewart Center, Purdue University, West Lafayette, IN. Contact: Edward J. Kompass, Control Engineering Magazine, 1301 South Grove Ave., PO Box 1030, Barrington, IL 60010, telephone (312) 381-1840.

This year's conference celebrates the 25th anniversary of the application of digital computers to industrial control. Twenty-two applications papers will support the four specially-commissioned, two-hour tutorials. Topics include: a view of the beginnings and development of digital computer-based industrial control, the merging of discrete and continuous process control, the beginning of computer-based digital control systems, and a future scenario for computer-based digital control systems. Applications papers cover: array processors, fiber optic data buses, micro and personal computer packaging for industrial applications, personal computer software packages for industrial control, industrial I/O for personal computers and the role of humans in fully computerized industrial plants.

25-27 September. International Industrial Controls Conference and Exposition (IIC '84). Philadelphia Civic Center, Philadelphia, PA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

Preliminary session titles include: *Advances in Information Flow Networks*; *Highways for Factory Automation*; *Vision*; *User-friendly Software for Programmable Controllers*; *Fiber Optics*; and *Robotics*.

OCTOBER

2–4 October. 14th International Symposium on Industrial Robots. Gothenburg, Sweden. Contact: Swedish Trade Office, 4000 Town Center, Suite 202, Southfield, MI 48075, telephone (313) 352-6990.

Nearly 1,000 delegates are expected to participate in this year's symposium. In connection with the symposium, there will also be an extensive international exhibition showing the latest developments and achievements in the field of industrial robots.

2–4 October. AUTOFACT 6. Anaheim Convention Center, Anaheim, California. Contact: Gregg Balko, Computer and Automated Systems Association of SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

AUTOFACT 6 will feature a comprehensive program of tutorials and conference sessions covering the entire spectrum of computer-integrated manufacturing—from design and engineering, through fabrication, assembly, inspection and testing, to shipping.

10-12 October. InteRobot-West '84. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

InteRobot-West '84 offers 20 technical conference sessions, three special-interest tutorials, and 80 internationally recognized speakers and session chairmen. Session titles include: *Industry Overview*; *Tooling Design*; *Machine Languages*; *Machine Vision*; *Machine Sensors*; *Robots in the Foundry*; *Personal and Educational Robots*; *Education in Robotics*; and *Emerging Robot Applications*.

 Circle 5

Letters

Improved Computer Interface

I'm writing in regard to Paul H. Muller's "A Simple Computer Interface for Robotics Experimenters" (March 1984). Referring to the diagram in figure 1, the author states that "when bit D_0 is high . . . a small amount of current flows from the port to ground through the 2N2222 base-emitter junction." When bit D_0 is high, a *large* amount of current will flow from the port to ground. Using the transistor as described in the circuit will result in a short-circuit, possibly damaging the computer's power supply. A current-limiting resistor must be used in series with the transistor's base connection. A 1k Ohm resistor will allow approximately 5 mA to flow through the emitter-base junction, thereby "activating the transistor's collector-base junction . . . ," protecting your computer's power supply, and preventing the transistor from burning itself out.

Mike Andre
RD#4 Box 52
Boyertown, PA 19512

Well-Balanced Bipeds

Your article on *Bipedal Balance* (Thomas A. Easton, April, 1984) is one of the best articles I've read in your magazine since I discovered *Robotics Age* last October.

Many of the articles in your magazine interest me not because of the circuitry diagrams, but rather because of the descriptions of what these machines are capable of now, and the possibilities of what a more sophisticated version might be capable of in the future.

I am a nonengineer, which is to say that I'm interested in robotics but don't have the electrical or mechanical background necessary to be more than mildly interested in a page talking about transfer carriages or pallet supports.

I've enjoyed the issues of *Robotics Age* that describe the creation of new and more diverse sensors and functions, but the article on bipedal balance speaks of an entirely new level of robot that promises to be as different from the HERO as the space shuttle is from the first airplane.

I enjoy your magazine more because of this very interesting article. Thank you.

Herbert A Kroeze, III
5231 Matador Court #12
Tampa, FL 33617

Ribbon Cable Source

I hope you can help me. Some time ago I noticed a New Product announcement for a flat "ribbon" push-pull cable. I think the product was made by Du Pont. I have loaned out several

Letters

copies of *Robotics Age* and now cannot find the original reference. Can you help?

David Smith
Apt #8
1022 Okoboji Ave.
Milford, IA 51351

The product was indeed made by The Du Pont Company. The product is called Dymetrol elastomeric tape and was introduced in 1978. The material is light weight and suitable for use in a push-pull mechanical arrangement. For more information, contact: The Du Pont Company, Marketing Communications Department, Wilmington, DE 19898.

Attention Course Administrators

I am a high school teacher interested in instituting a robotics course on the secondary school level. It is my intention to make students aware of the history and future of this fascinating field. I am convinced that through the design and construction stages of a working model, they will learn valuable lessons in the physical sciences.

I would appreciate receiving any information from your readers which might relate to starting such a course. Any notes on successes or failures would be helpful.

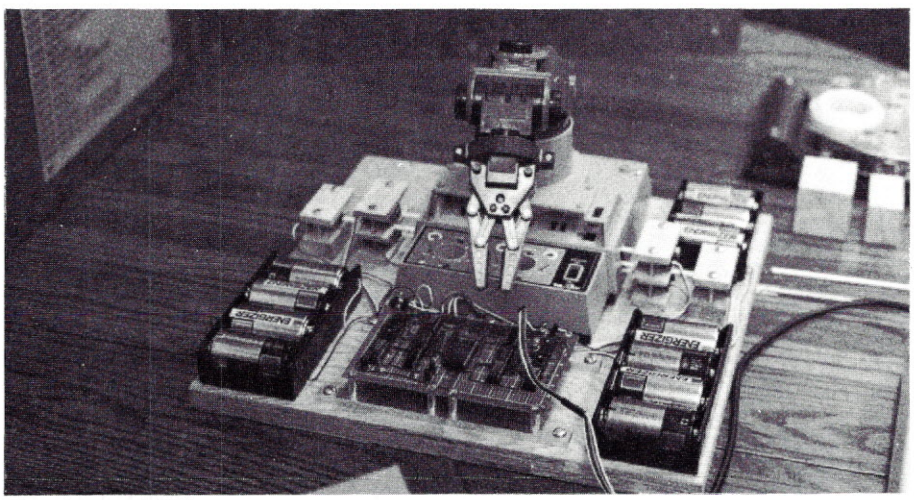
Edward J. Banas
Old North Road
RFD #1
Winsted, CT 06098

Robot Interest Group

I am in the process of forming an organization of people in the Dallas-Fort Worth area who share an interest in robotics. The organization will enable people involved in all aspects of robotics to exchange information and ideas. Those interested in both industrial and personal uses of robots will benefit. Plans include monthly general and specialized interest group meetings, a newsletter, and possibly a computer bulletin board.

Our meeting schedule and location have not been finalized. Anyone interested in learning more can contact me at the following address.

Joe S. Rowe
405 Tiffany Trail
Richardson, TX 75081
(214) 690-1575 (Home)
(214) 661-6428 (Business)



Armatron and VIC

I am a seventh grade student at St. Charles Middle School. Recently I entered a science fair project on an inexpensive computer-controlled robot.

I used the Armatron robot sold by Radio Shack and made an electronic interface to a VIC-20 computer.

Bearing blocks made of maple wood connected motor shafts to the gears inside the Armatron. Six motors were used to control the six different joints in the robot. A four-bit word from the VIC-20 port was decoded into 12 lines of data; two lines were used to command forward and reverse to each motor. Transistors were used as switches to power the motors with two 6 V power supplies. The project was built for $60.00, including the $32.00 for the Armatron.

I have won first place in my school science fair and received a special award from the Air Force. I have also been chosen to represent my school at the Northwestern New Mexico Regional Science and Engineering Fair.

Jimmy Banas

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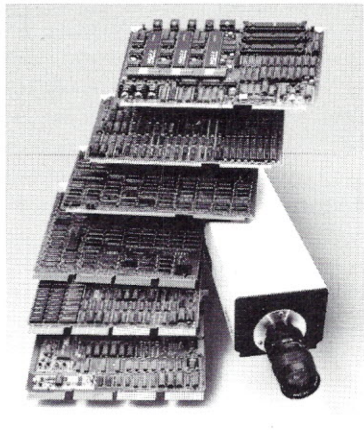

The IP-512 family of OEM image processing modules have set new standards with high performance features previously available only on systems costing much, much more.

The IP-512 is a **modular, real-time image processor** that's plug compatible with the INTEL **MULTI-BUS** and DEC **Q-BUS**.

It interfaces with a standard video source, stores images in single or multiple 512 × 512 frame buffers with up to 24 bits/pixel, and includes **pipeline processing** for real-time image averaging, summation, subtraction, convolutions, histograms, feature list extraction, erosion and dilation.

The modules contain programmable I/O Transformation Tables and provide for B&W and RGB output for full color processing.

Applications include **factory inspection, robotic vision, medical imaging, industrial radiography, teleconferencing, microscopy and image analysis**, among others.

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For details, call our Sales Department at (617) 938-8444. Or write to:

IMAGING

Imaging Technology Incorporated, 600 West Cummings Park, Woburn MA 01801 Telex: 948263

 Circle 15

Sensory Perceptions

SHAPE MEMORY ALLOYS. In March, this column described a robot hand developed by Hitachi which used Shape Memory Alloy as the motive force. The response to that small description was enormous. As a result, the July issue of *Robotics Age* will describe the Hitachi gripper and also discuss other uses of Shape Memory Alloys. For those readers who just cannot wait, you can reach Hitachi's consulting group at (212) 888-6996. If you are looking for additional information about Shape Memory Alloys, you might try Memory Metals, Inc. in Stamford, Connecticut. They can be reached at (203) 358-0437.

COMPUTER MATH PRIZE. The Fredkin Foundation has announced it will award $100,000 for the first computer to make a major mathematical discovery. Carnegie-Mellon University has been named trustee of the "Fredkin Prize for Computer Discovery in Mathematics." The prize will be awarded for a mathematical work of distinction in which some of the pivotal ideas have been found automatically by a computer program in which they were not initially implicit. Dr. Woody Bledsoe of the University of Texas at Austin will head a committee of experts who will define the rules of the competition.

According to Dr. Bledsoe, the purpose of the prize is to "stimulate the use of computers in mathematical research and have a good long-range effect on all science." The Fredkin Foundation gives a similar prize for a world champion computer chess system. Recently, $5,000 was awarded to Ken Thompson and Joseph Condon, Bell Laboratories researchers who developed the first computer system to achieve a Master rating in tournament chess.

MICHIGAN VISION. The Environmental Research Institute of Michigan (ERIM) a state-endorsed research institute in Ann Arbor, and Perceptron, The Machine Vision Company, have announced an agreement which will "enhance the ability of both organizations to provide state-of-the-art technology to machine vision and intelligent machine users."

Under an existing agreement, ERIM provides research and development to Perceptron in the area of cytocomputer technology, a form of image processing. The expanded contract will encompass sensor technology and algorithm development. In exchange, ERIM will receive a 5 percent equity position in Perceptron, a privately held corporation. Perceptron will also provide manufacturing support for certain advanced machine vision systems developed by ERIM.

The new program will be administered by the Intelligent Machine Technology Group at ERIM, directed by C. W. Swonger. Formerly vice president of research and development at Perceptron, Mr. Swonger is a nationally recognized expert in the development of computer-based systems for automatic image processing.

PARTS SOURCE. If you're looking for an inexpensive source for experimental robot parts, consider Herbach & Rademan, Inc. Their 32-page catalog, published seven times a year, is packed with items which will delight the experimentalist. One of their biggest sellers is a motorized wheel, which they have sold for years. The catalog also contains motors of all types, sensors, switches, relays, actuators, bells and whistles. And if after construction your robot is wounded, they even have a Purple Heart box which you can award your mechanical creation. Write for their latest catalog at: Herbach & Rademan, Inc., 401 East Erie Ave., Philadelphia, PA 19134.

FLAT LITHIUM BATTERY. Polaroid Corporation has announced the P500 Lithium Power Pack. Dimensionally identical to the Polaroid P100

Sensory Perceptions

Battery, the battery used in Polaroid cameras, the 6 V Lithium Power Pack features high-energy density, high capacity, a flat discharge profile, and an anticipated shelf life of over five years. The Lithium battery generates 6 V at up to 150 mA continuous drain. The P500 offers up to 1330 mAH of power.

If you wish to evaluate the P500 Lithium Power Pack for your applications, Polaroid offers a kit for $22.50 (#606166) which provides two P500 batteries and a molded battery holder. You can obtain more information from Polaroid Corporation, 784 Memorial Drive, Cambridge, MA 02139.

FROM ACCURACY TO ZERO POINT. The Robot Institute of America has published a glossary of robotics definitions. The 74-page pocket-sized *RIA Robotics Glossary* provides definitions of terms commonly used in robot product literature, sales presentations, and technical meetings. The glossary is available for $9.00 from The Robot Institute of America, One SME Drive, PO Box 1366, Dearborn, MI 48121.

ROBOT CHAMPIONSHIP. On June 15 and 16, the Robotics Championship of the Southeast will be held at the Science Museum and Planetarium in Palm Beach, Florida. High school and undergraduate college students are invited to enter. Financial support and total cash prizes in excess of $4,500 will be awarded.

The championship is divided into three categories. The high school category includes robots of any type. Judging will be subjective and based on originality of design, utility, quality of workmanship, and aesthetics. College category A requires a robot arm, mounted on a fixed platform, to pick up a filled, open, aluminum soft drink can and pour the contents of the can into a glass. College category B requires a mobile robot to find its way through an unknown maze with no external direction other than a command to start.

For more information contact The Science Museum, 4801 Dreher Trail, West Palm Beach, FL 33405.

AROUND AND AROUND THEY GO. According to a report by International Resource Development, Inc., new developments in gyroscopes and inertial positioning devices have reached the point that industrial robots will soon be equipped with them. The inertial guidance equipment will enable the robot to know where it is at all times, and thus be able to work in a much more versatile manner than today's bolted-down industrial robots. Coupled with vision and collision-avoidance electronics, the robot will be able to wander around the factory, attending to a variety of welding, painting, and machining tasks.

CONFERENCE PROCEEDINGS. The Conference on Robotic Intelligence and Productivity held at Wayne State University brought together experts in the robotics field, both from industry and academia. The focus was on the current robotics development and future directions that would enhance productivity. Keynote speakers ranged from Mr. L. R. Ross, Executive Vice President of Ford Motor Company, to Dr. Ernest Kent of the National Bureau of Standards. Conference paper themes included: sensors and future robot control systems, robotic intelligence and computer-integrated manufacturing, productivity via intelligent robotic systems, structural aspects of robot performance, robotic languages, force feedback control with pattern recognition techniques, machine vision research, and mobile robots in productivity.

The 225-page conference proceedings, priced at $30, can be obtained from the Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202.

Sensory Perceptions

WHAT JAPANESE INVASION? RB Robot Corp. has reached an agreement for exclusive distribution of the RB5X™ robot in Japan. Kitagawa Joho Kiki Co., Ltd., a 42-year-old electronics distributor based in Osaka, Japan, has committed to $744,000 in orders for the RB5X personal robots, robotic arms, voice/sound synthesis options, preprogrammed software modules, and other RB5X accessories. In addition to carrying the RB5X, Kitagawa Joho Kiki is the exclusive Japanese distributor for NBI word processors, Cado Systems, and Hermes computers and word processors.

DYNAMIC DESIGN. Large-displacement dynamics software has filled an important gap in design analysis by determining displacements and reaction forces of mechanical systems driven into nonlinear regions. Up to now, however, the process has been slowed by the need to enter geometric, constraint, and forcing data by hand. The increasing popularity of large-displacement dynamics is attracting the attention of turnkey CAD suppliers who are creating interface software to integrate the simulations into their systems.

Intergraph Corporation has produced large-displacement software that works with Mechanical Dynamics' ADAMS and DRAM programs. These programs operate through a preprocessor and other interfacing routines in Intergraph's Mechanism Element Modeling System (MEMS). The integrated programs provide designers with the ability to determine displacements and reaction forces of mechanisms under real-world operating conditions. This is accomplished without the linearity assumption inherent in modal analysis and related dynamics techniques, thus allowing the application of large forces that drive the analysis well into the nonlinear domain and have discontinuous effects.

Mechanical Dynamics can be reached at 555 South Forest, Ann Arbor, MI 48104.

HAVE YOU THANKED YOUR ROBOT TODAY? A study by Strategic Inc. of the management implications of robots indicates that the increased usage of robots in Japanese factories has improved workers' attitudes. This has resulted in better quality work and greater contributions from workers. The effects of robots were found to be pervasive throughout the companies studied, resulting in greater efficiency, improved product quality, less rework, reductions in inventory requirements, more flexibility in responding to market requirements, better worker safety, and better return-on-investment. The report ascribes the favorable reception to special efforts on the part of management to ensure a positive reception for robots on the factory floor.

Strategic, Inc. can be reached at PO Box 9747, San Jose, CA 95157.

TAKE THIS SYSTEM FOR A SPIN. Robotic Vision Systems, Inc. has received a cost-plus-fixed-fee contract for approximately $2,492,000 from the Department of the Navy for delivery of a propeller manufacturing and repair system. The three-dimensional vision-guided propeller inspection system will be the third of its kind constructed by the company and will integrate its inspection capability with robotic welding and grinding-related operations to form a large-scale, fully-integrated flexible propeller manufacturing cell. Robotic Vision Systems, Inc. is principally engaged in the development and manufacturing of three-dimensional sensor-based intelligent robotic and inspection systems for industrial and military purposes. They can be reached at 425 Rabro Drive East, Hauppauge, NY 11788.

Circle 23

Circle 21

Introduction To Numerical Control Programming

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One of the more influential developments leading to the current use of robotics was the introduction of numerically controlled machinery. Numerical control is defined as the use of numbers to control a process. It has evolved from such simple systems as the player piano, introduced in the 19th century, to a highly sophisticated system for automated manufacturing. Among the machines frequently controlled numerically are those for drilling and boring, welding, grinding, turning, milling, cutting, packaging, punching, stitching, typesetting, laser machining, and electrical discharge machining.

This article presents an overview of numerical control programming techniques and languages, their origin, development, current state, and future trends.

HISTORY

Early simple devices aside, numerical control really began at the Massachusetts Institute of Technology in the early 1950s. In 1952 the MIT servomechanisms laboratory introduced the first three-axis, tape-driven numerically controlled milling machine, which was retrofitted to a Cincinnati Hydro-tel. In 1957, industry installed the first NC machines, and by 1960, NC machines were widely available in point-to-point drill positioning applications. At the time, users programmed each machine instruction. From 1955 to 1960, MIT researchers developed a computer-assisted part programming language called Automatically Programmed Tools or APT. The programs were written on a large computer, and the instructions were stored on paper tape for transfer to the machine tools. During the 1960s and early 1970s, the emphasis was on direct numerical control (DNC), in which one large computer directly controlled the operation of many machines, thus eliminating the need for paper tape. This also helped monitor the manufacturing process.

The advent of the microprocessor in the 1970s resulted in an emphasis on computer numerical control or CNC, where a dedicated, stored-program computer performed all the control functions. These first CNC systems were packaged with the machine tool as well as retrofit kits for older machines. Computer-aided design (CAD) systems were developed in the late 1970s with numerical control programming capabilities. By the end of the decade, more than 60,000 numerically controlled machines were in use in the United States alone. In the last ten years, some of the first fully automated factories using robots, NC machine tools, and supervisory control systems began operation. Numerical control is a growing field with rapidly occurring advances in graphics, low-cost personal computing systems, and sensory technology.

BASIC CONCEPTS

NC programming is based on motion within a coordinate system. Most NC machine tools use the Cartesian coordinate system for specifying locations. Figure 1 shows sets of axes for a milling machine and lathe. There are new machines that may be programmed in polar coordinates as well. The coordinates in an NC program specify the destination of a particular motion given in absolute or incremental form. Absolute coordinates are located relative to a set position on the machine which, in most cases, is programmed by the operator. Incremental coordinates are located relative to the current position of the machine. Figure 2 is an example of the coordinates given in both absolute and incremental positioning.

NC control systems are often categorized by the path the tool takes between two specified locations. In the early days of numerical control, many systems were point-to-point or PTP. These systems move from one point to another but the path between these points is unspecified. This technique is useful for positioning a drill bit, but not for contour milling operations. Contouring systems control both the positioning and relative velocities of the axes. Hence, the path in between the locations can be specified.

Figure 3 shows two tool paths with the same beginning and ending coordinates, one with PTP control and one with linear interpolation contouring control. Typically, contouring control uses linear or circular interpolation to specify paths, although some machines allow parabolic and other forms of interpolation. In each

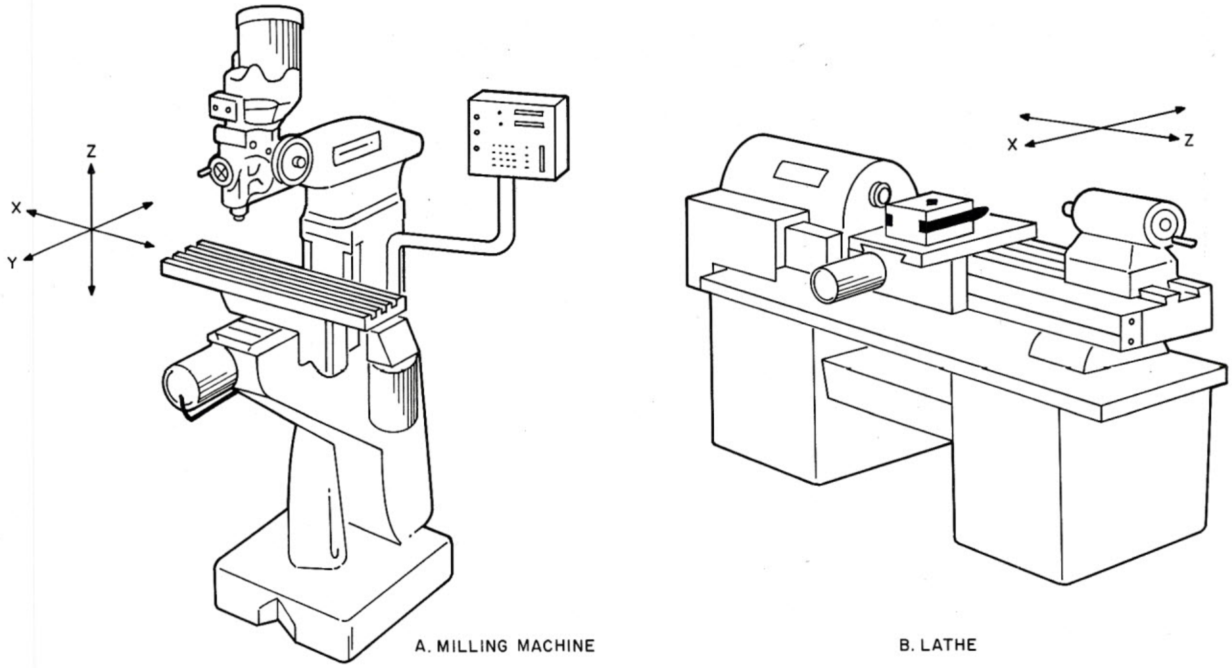

Figure 1. Axis orientations for a lathe and milling machine.

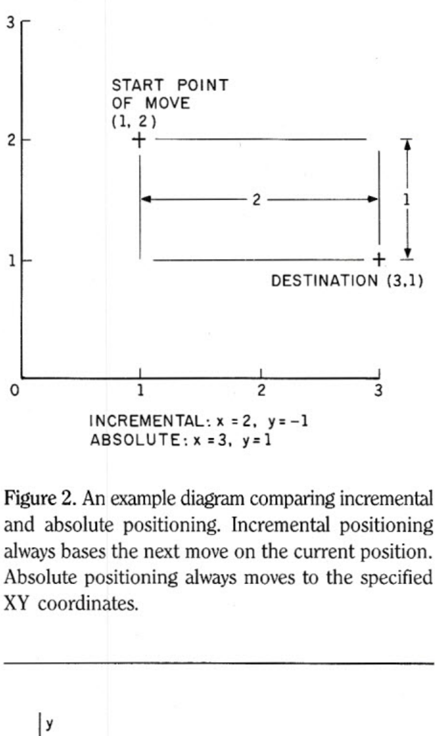

Figure 2. An example diagram comparing incremental and absolute positioning. Incremental positioning always bases the next move on the current position. Absolute positioning always moves to the specified XY coordinates.

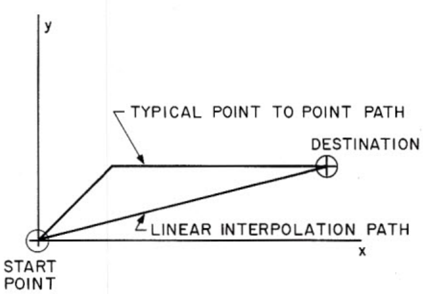

Figure 3. Comparison of point-to-point (PTP) versus linear interpolation paths. The point-to-point method does not specify the path taken between two points; linear interpolation defines the precise path taken between two points.

case, the path the tool takes can be specified in the same program line as the location to which it is moved.

Several types of media are used to store NC part programs. To date, the most commonly used medium has been the paper tape, which can be encoded in either EIA (Electronics Industries Association) or ASCII (American Standard Code for Information Interchange) standard tape format. There are two reasons why paper tape is still in common use, even though better forms of storage exist. First, there is a large installed base of tape-operated systems, so the availability of tape input on new machines maintains conformity within a shop. Second, paper tape is relatively resistant to damage within a dirty shop environment.

Magnetic tapes in cassette and reel form are also used, as well as floppy disks, which are used to an even lesser degree. Some manufacturers use bubble memory for storage and forms of solid-state memory like this will probably become even more popular.

NC PROGRAMMING

There are basically two forms of NC programming, manual part programming and computer-assisted part programming. In manual part programming, the operator writes a set of program statements, which run the machine at about the same level as a set of instructions given to a machinist performing the same task on a manually operated machine tool. The program statements (blocks) set up the coordinate system, the destination of the motion, and the feedrates and speeds for the machine in this motion.

Computer-assisted part programming uses a general-purpose computer to automatically prepare a manual part program. This is accomplished by defining the part geometrically and using simple commands to describe the tool path. Computer-assisted part programming can reduce programming time since the computer prepares the instructions for the machine tool.

MANUAL PART PROGRAMMING

The term *manual part programming* is left over from the days when paper tapes were prepared on a teletypewriter machine with no editing or computer assistance in the part programming. The advent of CNC allows programs to be prepared and edited in the controller memory. In both cases, the code is written in a form that can be transferred to and from paper tapes. Most NC machines work on a Cartesian coordinate system. A line of NC code, called a block, consists of a sequence number, preparatory codes for setting up the machine at this step, the coordinates for the destination, and additional commands, such as the feedrate to be used during the motion. A typical program block, using the

word-address format (the most commonly used format), might look as follows:

N5G01G91X.25Y3.1Z2.2F2

In this particular example, the N indicates the step or sequence number (5). There are two preparatory commands: G01 indicates linear interpolation, and G91 specifies that the given coordinates are incremental or relative to the current machine position. The destination is given by the coordinates in inches; X, Y, and Z. The last command in this sequence is F, the feedrate in inches per minute. (Units may change from machine to machine.) Each block is terminated with a carriage return, sometimes designated explicitly by EOB.

The EIA uses a standard (RS-274D) for the block format which lists the various assigned G codes and M codes and the format for each block of information. A partial list of these codes and their functions is given in table 1.

The following program is a good example of how users can write their own NC programs. This program mills a 1/8 in. slot along the path given by the quarter circle shown in figure 4 with a two-axis miller.

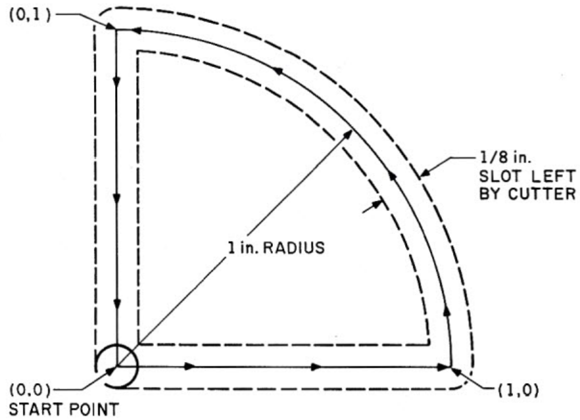

Figure 4. Sample manual part program to mill a 1/8 in. slot along the path given by the quarter circle shown.

left corner of the part at location 0,0. The tool moves to that location at a feedrate of two inches per minute. The initial line of code is:

N1G01G90X0Y0F2

The tool proceeds next to 1,0 at a feedrate of one inch per minute.

N2X1Y0F1

The cutting tool moves along an arc with a radius of one inch to 1,0 in a counterclockwise direction at the same feedrate. In this block, G03 stands for circular interpolation, counterclockwise direction, and the I and J coordinates stand for the distance from the center of the circle to the start point of motion.

N3G03X0Y1I1J0F1

The cutter completes the motion by moving back to 0,0 at a feedrate of three inches per minute. To end the program, the miscellaneous function M02 is used.

N4G01X0Y0F3M02

That was easy. But things sometimes get complicated when you want to mill the center of this quarter circle with an 1/8 in. diameter end mill. A diagram of the tool path is shown in figure 5 and the associated NC part program is shown in listing 1. Ignore the fact that sharp corners cannot be milled. Many blocks are written to remove the material in the middle, and the path of the cutter must compensate for its diameter. Manual part programming requires that all these paths be calculated and written in the same manner as the code above. Because of this complexity, CNC machines were improved to allow for manual data input (MDI) and computer-assisted part programming was developed to aid in the part programming process.

Some numerically controlled machines allow for the program to be entered directly at the machine console. These are called manual data input systems. These systems contain preprogrammed routines for pocket milling, roughing cuts, and other more complicated operations to reduce the number of blocks that the operator must enter explicitly. Video dislays are often used for interactive graphic display of the tool path and menu-driven prompting during

	Preparatory Functions (G-Codes)
Code	**Function**
G00	rapid traverse
G01	linear interpolation
G02	circular interpolation—cw
G03	circular interpolation—ccw
G04	dwell, length expressed in X or F word
G08	accelerate
G09	decelerate
G33–G35	thread cutting
G40–G44	cutter compensation and offset
G70	inch programming
G71	metric programming
G90	absolute coordinates
G91	incremental coordinates
	Miscellaneous Functions (M-Codes)
M00	stop machine until operator restart
M02	end of program
M03	start spindle—cw
M04	start spindle—ccw
M05	stop spindle
M06	tool change
M07	coolant on
M09	coolant off
M10	clamp workpiece
M11	unclamp workpiece
M30	end program and rewind tape

Table 1. Some commonly used G-codes and M-codes.

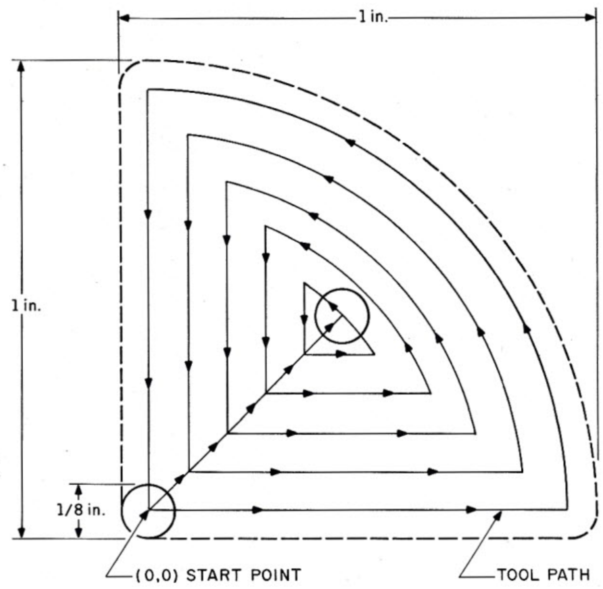

Figure 5. The tool path for a pocket milling example with manual part programming.

```
N10G01G90X.0625Y.0625F1.5
N20X.9375Y.0625F1
N30G03X.0625Y.9375I.9375J.0625F1
N40G01X.0625Y.0625F1.5
N50X.1509Y.1509
N60X.8491Y.1509
N70G03X.1509Y.8491I.8491J.1509F1
N80G01X.1509Y.1509F1.5
N90X.2393Y.2393
N100X.7607Y.2393
N110G03X.2393Y.7607I.7607J.2393F1
N120G01X.2393Y.2393F1.5
N130X.3277Y.3277
N140X.6723Y.3277
N150G03X.3277Y.6723I.6723J.3277F1
N160G01X.3277Y.3277F1.5
N170X.4161Y.4161
N180X.5839Y.4161
N190G03X.4161Y.5839I.5839J.4161F1
N200G01X.4161Y.4161F1.5
N210X.5045Y.5045M02
```

Listing 1. Manual part program for figure 5.

a programming session. Programming is much simpler using these programs because users enter the part dimensions directly and the program then accounts for tool dimensions to determine the tool path.

COMPUTER-ASSISTED PART PROGRAMMING

The above approach to NC machining becomes tedious and complicated when a large number of different parts must be machined using numerous redundant operations, or when different machines in the same shop must be used. This is when computer-assisted part programming is useful.

Computer-assisted part programming reduces machine programming time and improves the use of machine tools, by using a general-purpose computer to prepare instructions for a numerically controlled machine. These programs are divided into two parts: defining the workpiece geometry and specifying the tool path and machine operations. Programming languages developed for this task include APT, COMPACT II, SPLIT, ADAPT, UNIAPT, and GENESIS II.

To illustrate this approach, the slot that was milled in the discussion above will be described using APT (Automatically Programmed Tools), the first and probably most commonly used program. The standard for its format is ANSI X3.37.

Figure 6 shows the first pass of the miller in figure 5 that will be described using APT. First, the machine must be selected. Next, the part's geometry will be defined. The points and lines of this definition are shown in figure 6. Finally, the tool path will be defined and is described as shown in listing 2.

The tool path can best be described by imagining the lines and circle as picket fences. Imagine you are the tool. You start from P0, *(FROM/P0)*, and walk to the intersection of the two fences, LN2 and LN1, on the plane PL1: *(GO/TO,LN2,TO,PL1,TO, LN1)*. You are now standing to the left of fence LN2: *(TLLFT)*. You go left along the fence, LN1, until you reach fence C1: *(GOLEFT/LN1,TO,C1)*. Next you turn left

```
                             APT Example
                                    PARTNO/QUARTERCIRCLE
Describe machine type and tool      MACHIN/MILL
diameter                            CUTTER/.125

                                    PO=POINT/0.25,0.5,0.0
                                    P1=POINT/0.0,0.0,0.0
                                    P2=POINT/1.0,0.0,0.0
describe part geometry              P3=POINT/0.0,1.0,0.0
                                    LN1=LINE/P1,P2
                                    LN2=LINE/P1,P3
                                    C1=CIRCLE/CENTER,P1,RADIUS,1.0
                                    PL1=PLANE/P1,P2,P3

                                    SPINDL/1000
                                    COOLNT/ON
start machine up                    FEEDRAT/2.0

                                    FROM/PO
                                    TLLFT,GO/TO,LN2,TO,PL1,TO,LN1
                                    GOLFT/LN1,TO,C1
direct tool around toolpath         GOLFT/C1,TO,LN2
                                    GOLFT/LN2,TO,LN1
                                    GOTO/PO

                                    COOLNT/OFF
shut down machine                   END
                                    REWIND/1
                                    FINI
```

Listing 2. Sample APT program.

and follow along the circular fence C1 until you reach fence LN2: *(GLFT/LN2,TO, LN1)*. You turn left and follow fence LN2 until you arrive back at the intersection of fences LN1 and LN2: *(GLFT/LN2,TO,LN1)*. Finally, you trudge back to P0: *(GOTO P0)*.

There are canned routines in APT and other languages for pocket milling and roughing cuts, sometimes called area clearance programming. These can be used to create programs like that shown in listing 1 in a few program steps.

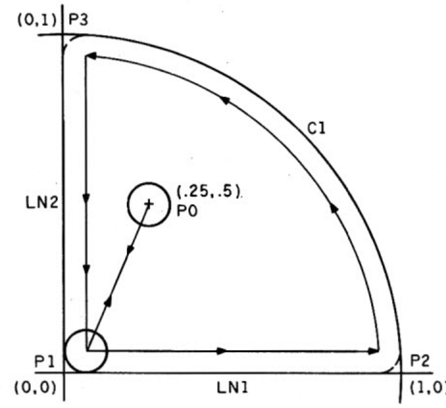

Figure 6. The APT command codes shown in this diagram mill the inside of a 1/8 in. slot inside the quarter circle shown.

The computer-assisted part program takes the user's input and creates a file, sometimes called a CL (centerline) file, which represents the tool path of a general machine tool. Next, a postprocessor generates the manual part program for the specific tool involved. The postprocessor also includes the limitations and special functions of this specific machine tool.

Computer-aided design (CAD) can be used in conjunction with the computer assisted parts programming by a shared data base in the workpiece geometry. The power of CAD systems is evident in their ability to use interactive graphics to rapidly create data bases that describe the geometry of a part. The data bases can also be used for engineering analysis and geometric modeling. Sometimes, the tool path can also be entered graphically on a CAD system. The output of a CAD system would be a CL file, or if a postprocessor were included, a manual instruction file.

Some limited capability CAD-like systems function as dedicated NC part programming systems. These systems use the programming and graphics of computer-aided design at a fraction of the cost of a complete system. They also use conversational prompting for each program entry.

FUTURE TRENDS

NC technology has seen tremendous improvements in the last few years; a trend that will undoubtedly continue. The microcomputer is already in the hearts of many CNC systems, but its impact is just beginning to be felt. Numerical control part programming languages are often memory-intensive; some versions of APT require 256 Kbytes of memory or more. In

the past, this would have required the use of an expensive minicomputer system, but advances in memory technology have made personal computers with this amount of memory available at a reasonable cost. In the future, entire CAD/CAM systems for small shops may be based on a computer system of this type. Low-cost CAD systems sell at prices from $20,000 to $50,000. As the technology matures, prices will be even lower and capabilities will increase.

Another area of interest for the future is sensory capability. Limited capability for adaptive control, in which the machine automatically accounts for tool wear and other factors, is presently available on some systems. The major limitation is the lack of low-cost, reliable sensors to monitor machine performance. As these sensors become available, more software will be developed both for adaptive control and for diagnostic purposes.

As the technology of small computers and microprocessors matures, more emphasis will be placed on distributed processing, in which a number of processors performing specific functions—such as graphics display control and tool indexing—are interconnected to do those tasks formerly performed by a single large computer. This advance will allow greater modularity in NC systems, leading to lower cost and higher performance.

In the future, machine tools will accept a higher level of input. For example, input to a machine controller may be at the CL level or the APT source code level. More automated decision making will result in the ability to automatically select appropriate tools and toolpaths for optimal machine performance.

Finally, NC machine tools will become more compatible with total flexible manufacturing systems, robots, and supervisory computer systems. Some automated factories already exist where robots, machine tools, and automatic warehouses work in harmony.

The author wishes to thank Charles Dimarzio, Clyde Fitz, and Paula Donovan for their assistance in the preparation of this article.

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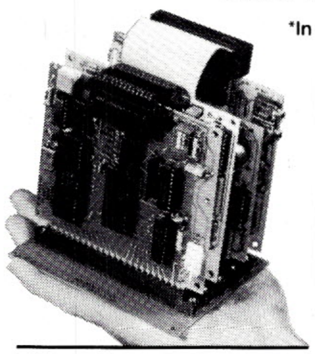

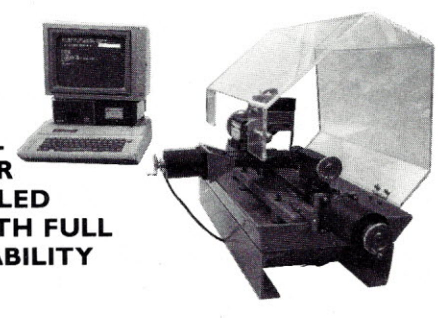

GLOSSARY OF CNC AND MACHINE TOOL TECHNOLOGY

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Palo Alto, CA 94303

CAD (Computer-Aided Design). A system which uses a computer to create or modify a design. Systems range from simple computer drafting systems to elaborate engineering systems capable of finite element analysis or VLSI chip design.

CAM (Computer-Aided Manufacturing). A system which uses a computer in the control of a manufacturing process. Systems range from two-axis CNC programming aids to full factory automation.

Circular Interpolation. A CNC programming code which controls the position and velocity of two machine slides in constantly varying fashion. Both slides start and stop at the same time.

CNC (Computer Numerical Control). Use of a dedicated computer to control some aspects of a numerically controlled machine tool. Systems range from simple single-axis drilling machines to multi-axis machining centers.

Continuous Path CNC. Capability of computing a continuous tool path based upon a set of end points. Required for Circular and Linear Interpolation.

Depth of Cut. The distance into the raw material that the tool cuts per pass. (Figures 1, 2, 3, 4, and 5.)

Down Milling. The operation of a milling cutter such that it rotates in the direction the material is being fed. Down milling forces the part into the table. (Figure 4.)

Engine Lathe. The most common form of lathe. May be mounted either on a bench or pedestal. Sizes normally range up to 24 in. swing and 48 in. center distance. (Figure 6.)

Face Milling. A milling operation in which angles to the axis of the spindle and part. Used to produce a flat surface. (Figure 1.)

Feed. The action of moving the cutting tool into the material. Commonly measured in inches-per-revolution of the part or cutter. (Figures 1, 2, 3, 4, and 5.)

Horizontal Milling Machine. A milling machine in which the axis of the cutting tool is parallel to the table.

Linear Interpolation. A CNC programming code which controls the position and the cutter axis is at right angles to the finish surface. Most of the cutting is done at the side of the cutter. (Figure 3.)

Facing. Commonly a lathe operation in which the cutting tool moves at right

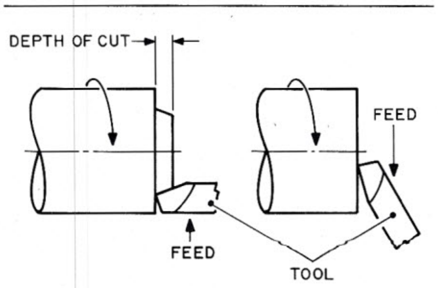

Figure 1. Lathe terminology for facing applications.

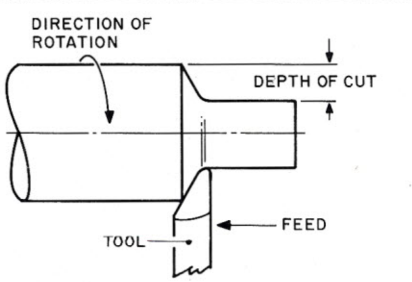

Figure 2. Lathe terminology for turning applications.

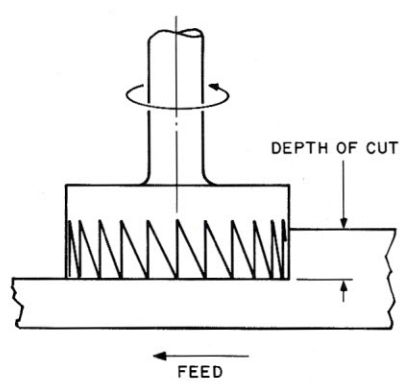

Figure 3. Milling machine terminology.

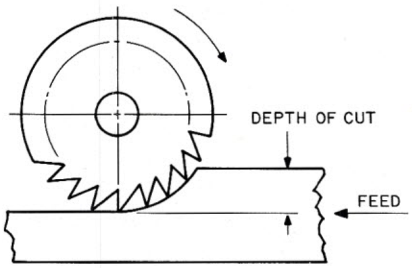

Figure 4. Peripheral down milling.

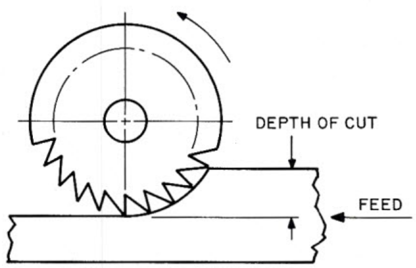

Figure 5. Peripheral up milling.

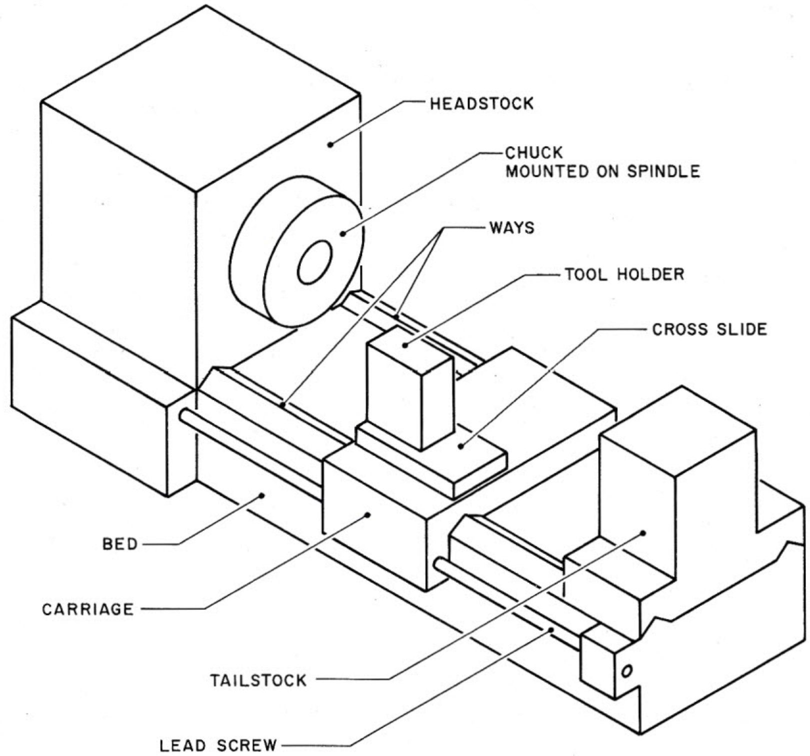

Figure 6. Basic lathe components.

velocity of two machine slides at constant but possibly different rates, thus producing a straight line path.

Machining Centers. Commonly a large machine tool capable of automatic tool changing and multi-axis machining.

NC (Numerical Control). A method of controlling the actions of a machine by numbers. The numbers may be supplied

by paper tape, magnetic tape, computer memory, or any other means.

NC Codes. A somewhat standardized system of simple codes for controlling the action of machine tools. A typical command would include a Numerical code (N-codes) to denote sequence, a Preparatory code (G-codes), followed by some coordinate information. For example: N100 G01 X120.00 Y60.00 translate into "Use Linear Interpolation and move from the origin (0,0) to a point at (120,60)."

Parting. A lathe operation in which a portion of the material is cut off by using a narrow tool fed into the material at a right angle to the axis.

Part Program. A computer program that describes the operations to be performed by a machine tool. The program is written in a high-level language such as APT that allows the programmer to describe the operations more easily than with NC codes.

Peripheral Milling. An operation commonly performed on horizontal milling machines in which the cutting action takes place predominantly at the outer diameter of the cutter. The cutter axis is parallel to the table. The milled surface contour corresponds exactly to the shape of the cutter's teeth. (Figures 4 and 5.)

Post-Processor Program. A program which links the NC machine to an NC computer running a Part Program. The Post-Processor Program is written for a specific machine and translates the Part Program into codes the NC tool can understand.

Screw Machine. An automatic lathe controlled usually by a series of cams that can perform a sequence of operations repeatedly without the need for an operator. Originally developed to make screws, bushings, and other small parts.

Straight-Cut CNC. A positioning system that only allows for motion along one of the axes or at a 45-degree angle. Useful for drilling machines and simple lathe operations.

Swing. The largest diameter part that can be placed in a machine tool with its center located on the spindle centerline.

Tape Control. The control of NC equipment by means of a 1-in.-wide punched tape. The standard code used in the USA is EIA RS-244. Tapes are read by means of photoelectric cells or electrical contacts.

Turning. A machining process commonly performed on a lathe which produces a cylindrical or conical shape by feeding a cutting tool into the material in a longitudinal direction (Figures 1 and 2.)

Turret Lathe. A lathe in which the cutting tools are premounted in the periphery of a circular holder. The holder is rotated to change the tool. The holder or turret may be mounted on the cross slide or at the tailstock. Its primary advantage is the saving in time normally required to install a new cutting tool when more than one type of tool is required to make a part.

Up Milling. The cutting action of a milling cutter when it is rotating against the direction of material feed. Tends to pull the part up from the table. (Figure 5.)

Vertical Milling Machine. A milling machine in which the axis of the spindle is perpendicular to the table. (Figure 7.)

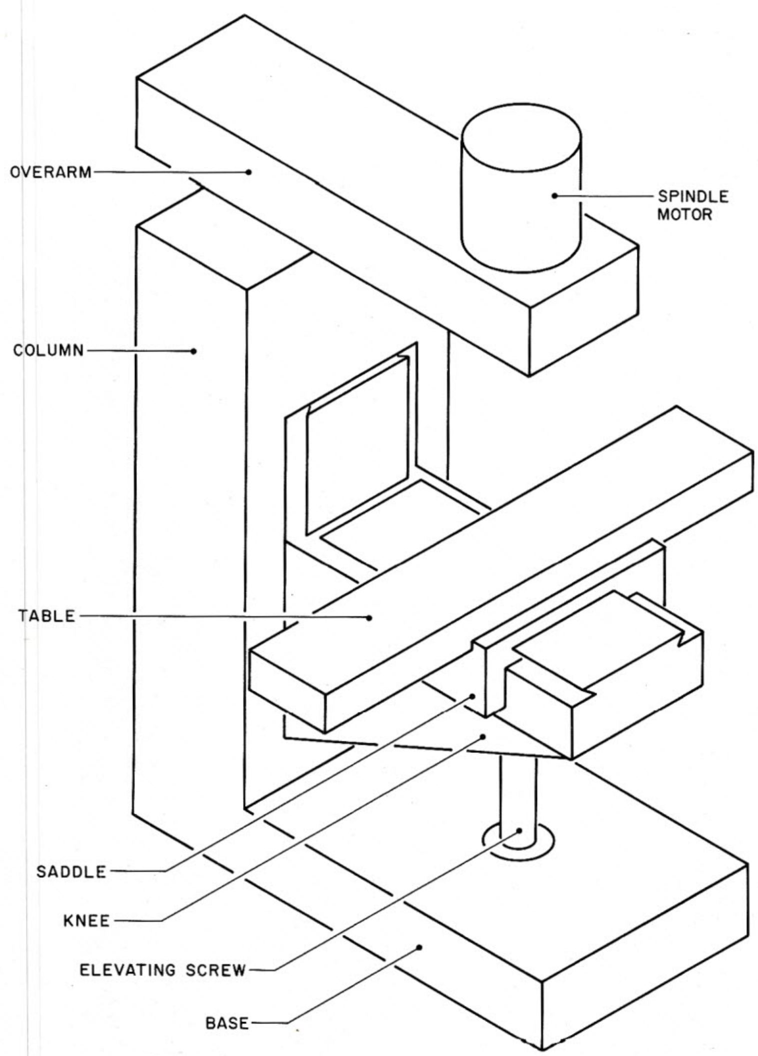

Figure 7. Basic vertical mill components.

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A Glance at Some Microprocessor-Controlled CNC Tools

Staff
Robotics Age

Microprocessors have invaded the machine tool industry. Some of the new light industrial CNC tools are designed specifically to be controlled by standard personal computers. Although some of the machines use custom-built interfaces, a standard eight-bit parallel port is often used for computer-to-CNC machine communications.

The following product descriptions, and their accompanying specifications, were garnered from company product literature. Contact the companies to receive further information.

Colne Robotics/D&M Computing, Inc. The Colne 5 CNC lathe is distributed in the United States by D&M Computing, Inc. The lathe is designed for use in the educational environment as a training tool for introducing students in high school and college to industrial automation and to the capability and potential of advanced computer numerically controlled systems. The D&M concept is to allow the use of the individual institution's present computer systems to operate the Colne 5 CNC. The lathe is controlled from a standard eight-bit parallel port.

The lathe bed is mounted in a tray that supports the head and tail stocks, the saddle and the cross slide. The DC motor is bracket-mounted to the rear of the headstock. It drives the chuck via a pulley. A tachometer feedback provides speed stabilization under load.

The X stepper motor is mounted to the rear of the saddle and the Z stepper motor to the bed. The stepper motors drive recirculating ball leadscrews to give X and Z movements accurate to better than 0.025 mm.

Table 1.

Colne 5 CNC Lathe Specifications

Chuck Size:	80 mm
Swing over bed:	130 mm
Swing over cross slide:	80 mm
Distance between centers:	325 mm
Speed range:	0 to 2500 rpm
Dimensions:	680 mm long by 445 mm deep by 240 mm high
Weight:	40 kg
Interface:	Standard eight-bit parallel port.

Stabilized DC. Variable speed drive. X and Z drives. 200 step high-torque stepper motors and software for at least 100 blocks.

The control software provides a comprehensive range of industry standard G-codes and the facility to accept and retain complex cutting sequences. A variable-scale emulator provides graphics for tool path verification. Other software features include editing, updating current software block, and safety measures. Software is currently available for the BBC, Apple, and Commodore 64 computers.

A lockable safety cut-out button to disable the DC motor is positioned conspicuously on the front control panel. A transparent guard covers all moving parts when motors are running. A safety switch insures motor cut-off when the guard is raised. A similar interlock protects the end cover plate. As an added safety feature, the stepper motors withdraw the cutting tool to a safe position as the DC motor runs

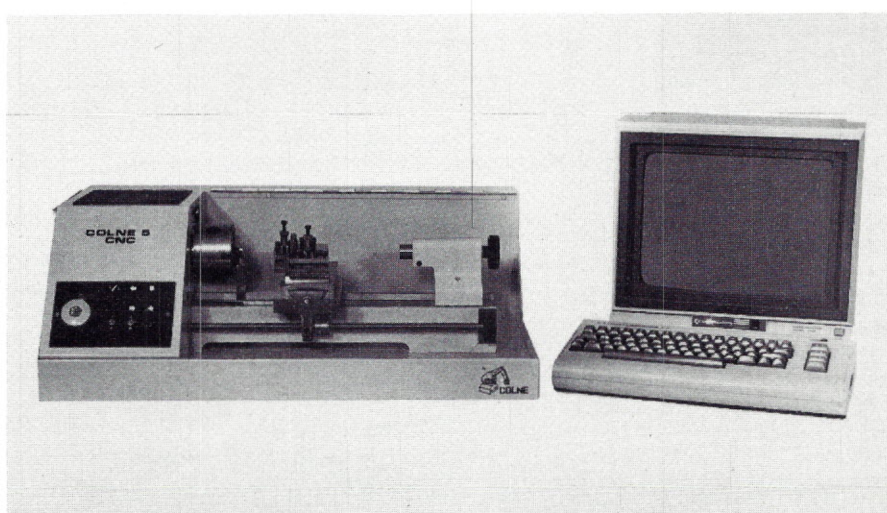

Photo 1. Colne Robotics/D&M Computing 5 CNC lathe.

down. Microswitches at the limits of +Z and −Z travel prevent the saddle from overrunning the bed.

A detailed and comprehensive handbook and a separate operator's guide and exercise manual are supplied. A set of tools and ancillaries are provided with each lathe.

For more information, contact: D&M Computing, Inc., Box 2102, Fargo, ND 58107, telephone (701) 235-7743.

Light Machines Corporation. The spectraLIGHT from Light Machines is an inexpensive CNC lathe designed to work with most popular personal computers, including the IBM PC and the Apple II. It can create surfaces of revolution in wood, plastic, or metal within a working volume of 3.5 in. diameter by 8 in. length. The control software allows you to write your instructions in conventional, industry-standard NC code. You can also add special functions, such as polynomial-fit curve cutters or tool force sensors. Programs can be created on diskette and recalled for repeated use.

The spectraLIGHT provides a resolution of 0.0003 in. along both axes of movement with repeatability of ±0.0001 in. All backlash effects are removed in software and adjusted by keyboard command. The lathe head features lifetime lubricated bearings with adjustable preload. The gib slides contain adjustable low-friction inserts to eliminate lateral play.

Four operational modes are available for the spectraLIGHT. Program Mode allows

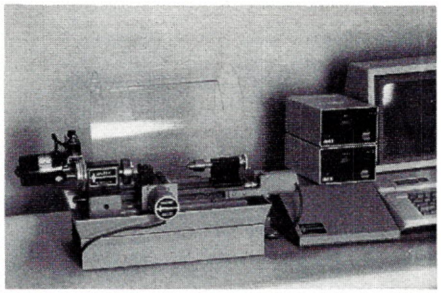

Photo 2. Light Machines Corporation spectraLIGHT CNC lathe.

you to write and edit numerical control machine code, run it, and store it for repeated use. The program allows both absolute and incremental tool positioning along any straight line or sequence of such line segments. You are also in full command of the feed rates. Jog Mode allows you to move the lathe at specified intervals at a chosen speed along each axis of travel, using the arrow keys on the keyboard. For simple machine operations, this is simpler, less fatiguing, and more precise than operations with a conventional manual lathe. Scan Mode provides adjustable velocity XY movement using the arrow keys or optional joystick for easy positioning of the tool tip at the beginning of the cutting operation or for the cutting itself. Initialization Mode allows you to enter values for backlash control from the keyboard. This mode is also used for setting zero position for absolute positioning in the program.

For further information, contact: Light Machines Corp., 9 Constitution Drive, Bedford, NH 03102, telephone (603) 472-8300.

Table 2.

Light Machines Corporation Microlathe PC Specifications

Swing over bed	3.50 in.
Swing over carriage	1.75 in.
Distance between centers	8.00 in.
Spindle inside diameter	0.405 in.
Spindle nose taper	No. 1 Morse
Spindle nose thread	¾ in. by 16 threads per inch
Cross slide travel	2.25 in.
Tailstock spindle travel	1.50 in.
Tailstock spindle taper	No. 0 Morse
Spindle speed range	200 thru 2000 RPM
Program and jog mode feed rates	0 thru 6 in./minute
Scan mode feed rate	0.015 thru 15 in./minute
Overall length	26⅞ in.
Overall width	15⅝ in.
Overall heigth	7⅛ in.
Required power	115 VAC @ 5A
Motor type	Permanant magnet steppers
Motor step travel	0.00025 in.

The Microlathe PC software is available for IBM PC, DEC LSI-11, and Apple II and Apple IIe computers. The control interface is a standard eight-bit parallel port.

Minitool, Inc. The Minitool, Inc. Model 2500 CNC numerically-controlled micro drilling machine features a low-cost, point-to-point programmable control system that provides both sequential and step and repeat patterning for the X and Y axes. The Minitool vee-bearing design assures accurate drilling guidance available.

The 2500 CNC consists of a base, step-motor-driven XY table, column, step-motor-driven infeed drill head (1.5 μm smallest increment) and separate numerical control unit. The numerically-controlled unit is compact, lightweight, highly portable and can be powered from a standard electrical outlet. There is no control language to learn and no tape to prepare. Entire programs, or portions of programs, can be quickly changed or repeated.

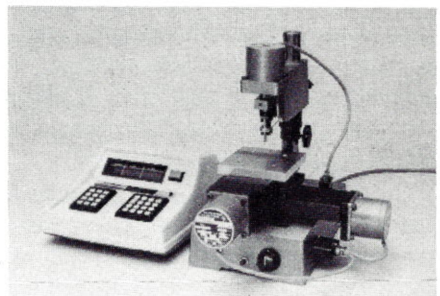

Photo 3. Minitool Model 2500 CNC numerically-controlled micro drilling machine.

Up to 99 program sequences can be stored. For each sequence, 100 step and repeat positions may be programmed for both the X and Y axes for a total of 10,000 positions. Control can be alternated among any of the operating modes—automatic, semi-automatic or manual—during positioning. An optional microcomputer-based controller, the Model 101, with memory recall and many other capabilities, is also available.

The Minitool 2500 CNC machine handles standard solid carbide drills (1/8 in. diameter by 1.5 in. long) as well as precision collet spindles with collets suitable of chucking high-speed steel, carbide and diamond micro drills.

For more information, contact: Minitool, Inc., 1334/F Dell Ave., Campbell, CA 95008, telephone (408) 374-1585.

OZO Diversified Automation, Inc. The Model 18 Overhead Coordinate Drilling Machine from OZO Diversified Automation, Inc. is a CNC programmable drilling tool. The Model 18 is designed for

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Table 3.

Minitool 2500 CNC Specifications

Machine head and base:	Special alloy casting, base blanchard ground.
Machine column:	28.6 mm diameter (1.125 inches) by 254 mm (10 inches) hardened and ground steel.
Motor:	24 VDC servo type.
Speed control:	Variable 0 to 7500 rpm, solid-state, built into machine base.
Power requirement:	115/230 VAC 45-400 Hz.
Vee-bearing mount:	Two in-line vee construction, interchangeable. Diamond vees standard.
Positioning table:	Precision lead screw type supplied with (commercial grade) 2 stepping motors. 50 mm (2 in.) travel in X and Y directions. Positioning accuracy 0.012 mm (0.0005 in.).
Positioning table:	Position lead screw type supplied with 2 (precision grade) stepping motors. 76 mm (3 in.) travel in X and Y directions. Positional repeatability 0.00127 mm (0.000050 in.). Linear accuracy 0.0025 mm (0.0001 in.). Squareness X to Y 15 ARC. SEC.
Drill infeed:	Stepping motor mounted over drill head. (Z-axis) Hardened and ground precision lead screw with carbide contact plate advances drill. Infeed programmable. Smallest infeed 1.5 um (about 62.5 millionths of one inch).
Drill capacity:	HSS to 0.05 mm (0.0019 in.). Carbide to 0.05 mm (0.0019 in.). Diamond to 0.13 mm (0.005 in.).
X-Y axis:	99 random positioning maximum. 10,000 step and repeat positioning maximum. Backlash compensated for X and Y movement.
Machine control system:	Absolute programming point-to-point.
Work clearance:	152.5 mm (6 in.) over machine base. 85 mm (3⅜ in.) over positioning table.
Dimensions (machine):	305 mm by 457 mm by 330 mm (12 in. by 18 in. by 13 in.)
Dimensions (computer):	229 mm by 330 mm by 127 mm high (9 in. by 13 in. by 5 in.)
Weight (machine):	22 pounds
Weight (computer):	5 pounds
Total shipping weight (USA):	35 pounds
Total shipping weight (Foreign):	45 pounds

drilling printed circuit boards and handles formats to 12 in. by 18 in. with a positioning accuracy of ± 0.0005 inc. The Model 18 fills the gap between huge multiple spindle mass-production drills and manual PC drills. It is particularly appropriate for limited production or prototype work.

This CNC tool is controlled by a personal computer and is easily used with menu-driven software. The programming scope and drill head are interchangeable. Once mounted, the programming scope is positioned with a joystick. Pressing a single button records the XY position in a coordinate file. The file is saved on diskette, ready to be used for drilling or to be edited as needed.

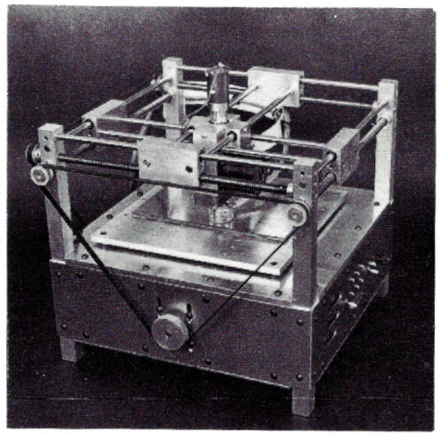

Photo 4. OZO Diversified Automation Model 18 Overhead Coordinate Drilling Machine.

When ready to drill, set the drill height, enter the total drilling depth, and start the drilling program. If drilling must be interrupted for any reason, the control program

Circle 20

Table 4.

OZO Model 18 Specifications

Performance	
Hit rate:	Up to 200 strokes/minute.
Maximum holes/hour:	27,000.
Positioning velocity:	100 in./minute.
Smallest increment:	0.0005 in.
Positioning accuracy:	±0.0005 in.
Mechanical Characteristics	
Table:	14 in. by 20 in.
Axis travel:	12 in. by 18 in.
Register pins:	⅛ in. with stationary pin bushing.
Bearings:	Recirculated linear ball bearings. Hardened bearing ways. Ball lead screws.
Positioning drive:	Stepper motors.
Machine dimensions:	26 in. by 32 in. by 15 in.
Weight:	About 165 pounds.
Electronics:	Air-cooled chassis. Solid-state power supply. Modular drive cards. Controlled by Apple II+ or Apple IIe computer.
Drill Head:	60,000 RPM drill motor. ⅛ in. chuck (set lock). Chip vacuum/pressure foot.
Scope:	5 in. by 5 in. screen. 5X magnifier. Illuminated head and optional video display.

remembers the point at which the interruption occurred. You can resume drilling from any point stored in an XY coordinate file. A vacuum attachment on the pressure foot removes the chips and dust generated from drilling. Other software options for printed circuit work include the ability to mirror and repeat patterns. The interface and software are available for the Apple II+ and the Apple IIe computers. An STD Bus interface will soon be available.

Since the typical circuit board contains 600 to 1000 holes, speed is an important design criterion. The OZO Model 18 can drill up to 27,000 holes through a stack of three PC boards on 0.10 in. grid centers. If drilling through a single board, speeds of up to 200 holes per minute can be achieved.

Although first designed as a PC board drill, interchangeable tools for other applications are planned. A routing head is the next option to be made available. An optical plotting head, wire wrap unit, and larger drill are also in the planning stages. For more information regarding your particular application, contact OZO Diversified Automation, Inc., 3380 South Dexter St., Denver, CO 80222, telephone (303) 756-6347.

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INTEL'S BITBUS MICROCONTROLLER INTERCONNECT

A Modern Method of Robot Communication

Peter I. Wolochow
Intel Corporation
5200 NE Elam Young Parkway
Hillsboro, OR 97124

In February 1984, Intel introduced a new bus communication architecture aimed at enhancing microcontroller-based applications. This article describes Intel's Bitbus—an interconnect scheme specifically designed to match the needs of high-performance, cost-conscious microcontroller applications. The Bitbus, along with the accompanying Distributed Control Module (iDCM™) family, provides the latest steps toward making the best use of VLSI technology in control applications.

BITBUS USES

Microcontrollers are a driving force in modernizing mechanical and electrical systems. They have replaced relays, wheels, and gears in applications ranging from automated manufacturing to process control. By incorporating at least one microcontroller, the total system cost of most control-oriented applications can be lowered while improving performance and leaving room for useful options. However, without an industry-wide standard on which to rely, most microcontroller applications lack a simple connection to other microcontrollers and control equipment.

Through advances in silicon technology, control systems have already made many evolutionary changes. Early systems relied on relay sequencers and simple alarm indicators. The PDP-8™ from Digital Equipment Corp. provided the first commonly used tool for coordinating many real-time controls. Microprocessors provided a simple way to reduce computer costs, but did not change system architectures until standard buses became popular. Industry standard bus architectures such as the Multibus® and STD-Bus™ have allowed designers to divide control tasks between many processors while taking advantage of standard modules from many vendors.

Microcontrollers have paved the road for the next step—distributed control. Most control-oriented systems distribute control functions to minimize system cost while improving system performance, responsiveness, and reliability. There are several ways to distribute control: a parallel bus structure, a simple set of control signals on individual control lines, a serial communications link, or custom technology. Each of these solutions requires considerable design effort, and often results in a performance-limiting interconnect matched to current applications but ill-suited for expansion or connection to a different control system.

Applications best suited for the Bitbus interconnect include robotics, numerically-controlled machines, process control, security systems, environmental control, and other distributed control and data collection systems. These applications typically use multiple controllers to physically distribute control, to improve system performance and reliability, and to reduce total system and maintenance cost. Existing data networks such as Ethernet, Token Bus, and various custom technologies are useful for transferring large data blocks at high speed, but also at a relatively high cost. What is still missing is a low-cost bus for local control environments. Combining the strengths of existing hardware and protocol standards with complete firmware and software support, the Bitbus interconnect provides a simple, standard technology for connecting distributed controllers.

BITBUS CONFIGURATIONS

The Bitbus microcontroller interconnect can connect a single master controller to a number of local or remote slave controllers. A multidrop configuration connects controllers (8044s) to a common bus. The single-chip *8044 microcontroller* contains two functional elements: an 8051 processor and an SDLC Serial Interface Unit (SIU). The onboard processor contains 4 Kbytes of read-only memory, 192 bytes of read/write memory, clock, timers, interrupt controller, and memory expansion bus. In Bitbus applications, the read-only memory is filled with special firmware routines that support the message-passing protocol, interact with user application tasks, and perform a series of power-up self-diagnostics.

Integral firmware allows each Bitbus controller to act as either a master or slave.

The master/slave relationship can be changed in real time. This provides a simple method for allowing backup master controllers. For example, you could program a backup master to wait for a poll from the primary master every second. If the master missed several polls, the backup could take control and switch itself from a slave to a master.

TRANSFER PROTOCOL AND MESSAGE FORMAT

The Bitbus interconnect is based on the SDLC (IBM's Synchronous Data Link Control) standard supported by the 8044. SDLC is commonly used by many vendors concerned about data integrity and interface standards. Since the SDLC protocol has limited overhead and a built-in data security and acknowledgement protocol, it is ideally suited for reliable transmission of short, control-oriented messages. To ensure a workable standard interface between Bitbus systems, additional protocol standards are included in the published Bitbus specifications.

The 8044 Bitbus microcontroller supports a large subset of the standard SDLC protocol. The 8044 manages SDLC traffic in Auto and Non-Auto modes with a minimum of interruption to the 8051 half of the microcontroller. In Auto mode (used by all Bitbus slaves), all SDLC functions are managed automatically with minimal effect on controller performance. In the Non-Auto mode (used by the Bitbus master), the controller can initiate transmissions and polls to slaves as well as process parts of the protocol not managed by the SIU (such as responding directly to each message and checking other status conditions). The 8044 component automatically manages all SDLC frame control, sequencing, and transmission procedures. In Bitbus applications, the 8044 also provides the message formats and sequence checks needed to guarantee proper delivery of critical control signals.

SDLC Protocol. SDLC is a bit-oriented data-link control protocol that defines a specific structure for each type of data and control exchange. As shown in table 1, each transmission type (I-frame, S-frame, and U-frame) is divided into identifiable fields. Each field contains one or more bytes of data and/or control information to accomplish the corresponding function.

Normal transmission between an SDLC

Transmission Modes

The Bitbus operates in either of two transmission modes: synchronous or self-clocking. In the synchronous mode, an external clock provides a data clock to transmit data at rates between 375 K and 2.4 M bits per second. In the self-clocking mode, the clock is derived from transition in the data using the NRZI (Non-Return to Zero, Inverted) encoding technique. Characteristics of each mode are shown below:

Synchronous Mode:
- 2.4 bits per second with external clock
  - Maximum of 30 m distance
  - Maximum of 28 Bitbus nodes

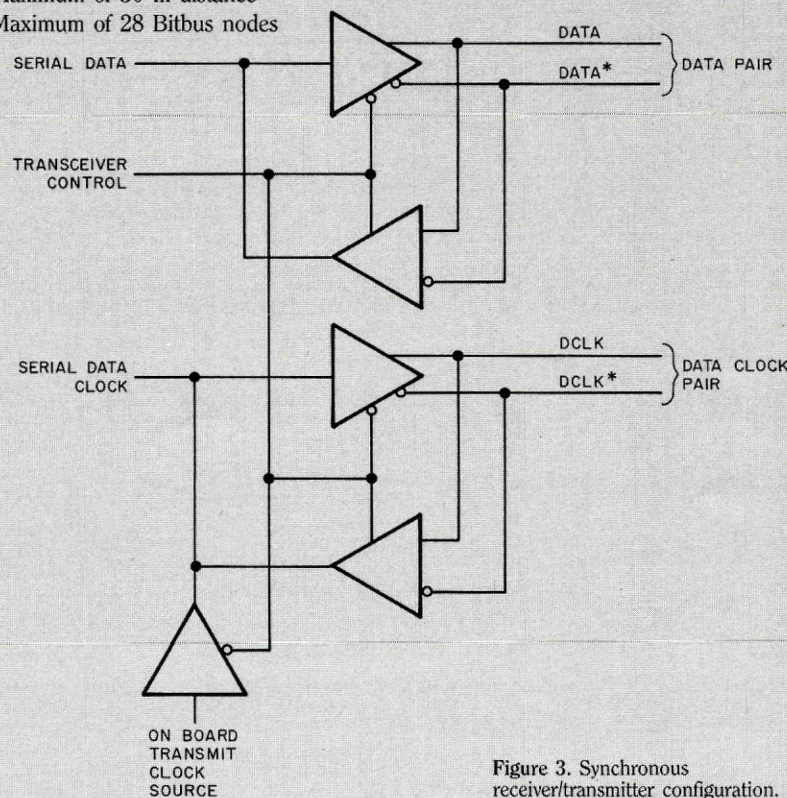


Figure 3. Synchronous receiver/transmitter configuration.

Self-Clocking Mode:

375K bits per second NRZI encoding:
- Maximum of 300 m between repeaters (total limit 900 m)
- Maximum of 28 Bitbus nodes between repeaters (limit 250)
- Maximum of 2 repeaters between the master and any slave

62.5K bits per second NRZI encoding:
- Maximum of 1200 m between repeaters (total limit 4800 km)
- Maximum of 28 Bitbus nodes between repeaters (limit 250)
- Maximum of 10 repeaters between the master and any slave

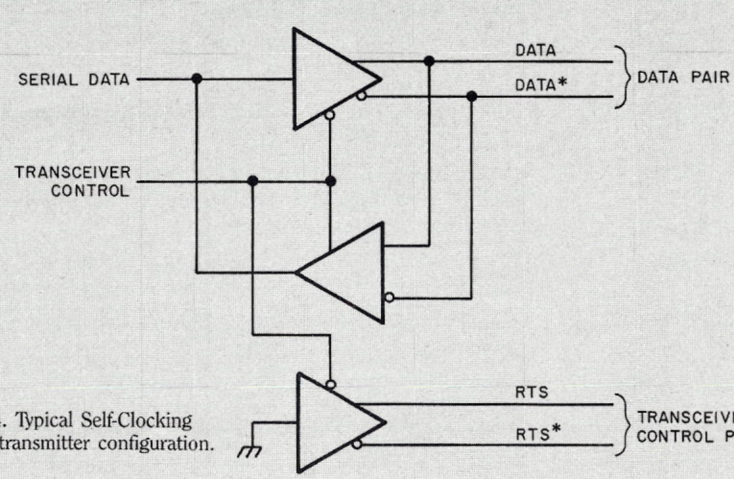


Figure 4. Typical Self-Clocking receiver/transmitter configuration.

RAC Function Commands

Every member of the 8044 family is programmed for Bitbus operation by including the iRMX 51 Executive and one system task, called the Remote Access and Control (RAC) function. The system task, responsible for managing the interface, provides a number of utilities to ensure that all Bitbus controllers can communicate with each other. The utilities also allow a master node to interact with slave controllers without having to write any 8051 code. The RAC function provides ten commands that let a remote master access local resource and status information and five commands specifically designed for intelligent remote control. Tables 3 and 4 describe the available access and control RAC functions.

The control functions can be used for higher-level utilities. For example, the Bitbus master can determine the existence of a special service task at a remote slave, and download programs depending on high-level system requirements or environmental influences such as service options or power failures. This test-and-program function could be accomplished by sending a GET_FUNCTION_IDS command and sending a group of WRITE_EXTERNAL_MEMORY messages to download an appropriate program, and then starting the program by sending a CREATE_TASK command.

Table 3. Remote Access and Control (RAC) Access Functions

COMMAND	OPERATION
READ_I/O	Read external I/O location. Return result in reply message.
WRITE_I/O	Write byte to external I/O location.
UPDATE_I/O	Write byte to, then read byte from external I/O location. Return result in reply message.
OR_I/O	OR data with contents of external I/O location. Return OR'd value.
AND_I/O	AND data with contents of external I/O locaton. Return AND'd value.
XOR_I/O	XOR data with contents of external I/O location. Return XOR'd value.
READ_INTERNAL_MEMORY	Read contents of internal memory location. Return result in reply message.
WRITE_INTERNAL_MEMORY	Write data to internal memory location.
DOWNLOAD_EXTERNAL_MEMORY	Write data starting at external memory location.
UPLOAD_EXTERNAL_MEMORY	Read data starting at external memory location. Return result in reply message.

NOTES:
Internal memory locations are included in the 192 bytes of data read/write memory provided in the microcontroller. External memory refers memory outside the microcontroller—the 28-pin sockets of the iSBX 344 module and the iRCB 44/10 board. Each RAC Access Function may refer to 1, 2, 3, 4, 5 or 6 individual I/O or memory locations in a single command.

Table 4. RAC Control Functions

COMMAND	OPERATION
GET_FUNCTION_IDS	Execute iRMX 51 GET_FUNCTION_IDS command. Return resulting list in reply message.
CREATE_TASK	Execute iRMX 51 CREATE_TASK command using the specified Task Descriptor. Return resulting status in reply message.
DELETE_TASK	Execute iRMS 51 DELETE_TASK primitive using specified Task Identification. Return resulting status in reply message.
RAC_PROTECT	Suspend or Resume Remote Access types of service. Return resulting status in reply message.
RESET_STATION	Jump to initial code reset address. **NO REPLY IS RETURNED.**

master and slave starts with an exchange of U-frames to synchronize the frame sequence counters and other controls. The data exchange is accomplished with the I-frame and S-frame. The I-frame contains data for a slave or a response from a slave. S-frames are used to acknowledge data receipt or to poll a slave for data.

Bitbus Messages. The *user data* contained in the I-frames conform to a standard Bitbus message format. All messages contain a five-byte header describing the source and destination, along with other status and control information. Messages sent to, or from, the standard Bitbus firmware (see the RAC Function Commands text box) may also contain special information to perform common I/O operations. Up to 13 user data bytes may be transmitted at one time.

Bitbus controllers *require* each message to be answered—not just acknowledged. The SIU provides an SDLC acknowledgement for each message. Only the application task to which the message is sent can send a meaningful reply. The Bitbus master enforces this rule by continuing to poll a slave for its reply to each transmitted message. Separating the replies and acknowledgements helps give Bitbus systems additional performance by freeing the control link while a reply is generated.

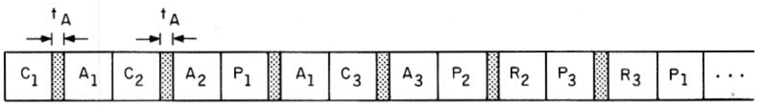
Figure 1 shows how several overlapping conversations can occur between the Bitbus master and slaves. The Bitbus master maximizes throughput by taking advantage of each slave's SIU ability to immediately acknowledge a message, without interrupting the 8051 processor. This removes the need to tie up the bus while waiting for the slave to calculate a response. The master can send commands to a controller and come back for the response later.

Bitbus traffic patterns and rules reflect the primary Bitbus purpose—control. The master controls all message traffic and initiates all messages. Slaves answer each message with either an immediate acknowledgement to confirm correct recognition, or with a response message associated with a previously received command. Whereas many SDLC-based systems suffer from large and unpredictable delays between a poll and a slave's acknowledgement, Bitbus slave controllers use the SIU to send an immediate answer. Because the response time is always short and predictable, no Bitbus bandwidth is wasted.

Table 1. Synchronous Data Link Control (SDLC) Frame Formats.

FRAME-TYPE	FORMAT	FUNCTION
I-frame	F A C—user data—FCS F	Information Transfer
S-frame	F A C FCS F	Supervisory Control
U-frame	F A C FCS F	Receiver/Transmitter Synchronization

NOTES:
'F' refers to the SDLC Flag byte; 'A' refers to the slave station's address; 'C' refers to the control field identifying the frame-type and other control parameters; 'FCS' refers to the frame check sequence (a 16-bit CRC calculated on all frame contents except the flags).



Where:

$C_1 \ldots C_n$=
Command messages sent by the master to the identified slave.

$A_1 \ldots A_n$=
Acknowledgements made by identified slave to message from master.

A_m=
Acknowledgement made by the master to a message from a slave.

$R_1 \ldots R_n$=
Response message sent by identified slave to the master. The master acknowledges these responses with the next appropriate poll or command to the identified slave.

$P_1 \ldots P_n$=
Poll sent by the master to identified slave asking for response message.

t_A=
Time taken to acknowledge a message or poll from the master.

Figure 1. Typical overlapping conversations possible with the Bitbus communications protocol.

Bitbus Message Passing. Messages are an integral part of any control-oriented application. Intel's entire Digital Control Module family supports the passing of short control commands, responses to these commands, and status information. A small executive program provides multiple tasking capability so that messages can be managed on a task-by-task basis. All Bitbus components and boards offer the same, simple, message-based interface to user applications that produce and act on control information in small messages. By using standard messages, 8044 tasks can perform I/O operations such as inverting a single I/O bit at a distant Bitbus node, without specially coded communications or bus management software.

BITBUS SPECIFICATIONS

The Bitbus hardware and software interfaces were selected to match distributed control requirements while conforming to established standards supportable with currently available electrical interfaces, cables, and operating systems. However, since some applications require different electrical and mechanical interfaces, the Bitbus connectors and bus interfaces provide additional signals such as power, RTS, DLCK, etc. By using these additional signals, other extensions such as simple fiber-optic communication links and optical isolators can easily be adapted to standard Bitbus connectors.

The Bitbus software interfaces also provide extra customization "hooks." For example, the Function ID Codes and the ability to create new tasks dynamically allow application tasks to take advantage of standard Bitbus services in custom—even proprietary—fashions. To assist in typical and custom designs, a complete Bitbus specification has been published which identifies all facets of Bitbus design.

The Bitbus uses the RS-485 interface as the physical link between controllers. The RS-485 electrical interface is an accepted variation of the common RS-422 interface that allows longer cable segments with more multidrop connections. Repeater stations make it possible to link concentrated control stations with additional remote data collection points. Repeaters are not supported in the Synchronous Mode.

INITIAL BITBUS PRODUCTS

The Bitbus microcontroller interconnect is supported by a number of new products. Using a preprogrammed 8044 called the iDCM Controller, the following products provide firmware, additional software, and flexible board-level support for distributed control applications. System-level controllers can take advantage of these modules to extend their I/O into the Bitbus realm. Component-level solutions can make use of the iDCM Controller, or use the software to configure unique solutions that are still compatible with different Bitbus systems.

iRMX 51 Real-Time Executive. The Bitbus firmware is based on a new member of Intel's iRMX Real-Time Operating System family, the iRMX 51 Executive, a very small multitasking executive that supports up to eight user tasks on any of the 8051 family of processors (8051, 8031, 8044, 8744, 8751, etc.). The Executive provides the basic utilities for users to create and maintain tasks, manage interrupts and time intervals, and pass messages between local and remote tasks. Table 2 shows all ten available commands.

The primary operation of the Executive centers around its ability to send messages between tasks residing on the same microcontroller or on another one. As the supporting system for Bitbus firmware, the Executive has been optimized to transfer messages with a minimum of delay. As a general-purpose, real-time executive, it directly supports user tasks located in memory. The first task (task 0) is reserved for a system task, called the RAC function that performs all Bitbus-related functons and provides some user, application-level services.

iRMX 510 DCM Support Package. The

Table 2. iRMX 51 Commands

COMMAND	FUNCTION
RQ_SEND_MESSAGE	Sends a message (a command from the BITBUS master, a response from a slave, or a simple message between tasks on the same BITBUS component) to another task.
RQ_WAIT	Waits for an interrupt, an event time-out, a message, or any combination of the three.
RQ_CREATE_TASK	Causes a new sequence of code to be run as an iRMX 51 task with a specific Function Identification Code.
RQ_DELETE_TASK	Stops the specified task and removes it from all execution lists.
RQ_ALLOCATE	Allocates a fixed-length buffer from the internal 8044 RAM for use as a BITBUS message buffer.
RQ_DEALLOCATE	Returns a BITBUS message buffer to the system.
RQ_GET_FUNCTION_ID	Provides a list of the 8 function identification codes representing the tasks currently operating on the microcontroller.
RQ_SET_INTERVAL	Set the time interval to be used as a separate event-timer for the task.
RQ_ENABLE_INTERRUPT	Allow external interrupts to signal the microcontroller.
RQ_DISABLE_INTERRUPT	Stops all external interrupts from signalling the microcontroller.

package contains software utilities to assist 8044 users in implementing Bitbus-based applications. They include software drivers for interfacing Intel's iRMX 86, 88, 286R, and iPDS ISIS operating systems to Bitbus boards and components. Remote I/O points, from a high-level task, may be controlled using the supplied drivers just as though they were attached directly to the master processor. The 510 package also includes developmental aids, such as a collection of literal definitions and a copy of the Bitbus firmware for use with in-circuit emulators, like the ICE-44, for Intel development systems.

iSBX 344 Bitbus Expansion Module. The module is an 8044-based, double-wide iSBX module, having two 28-pin memory expansion sockets, for driving distributed control systems as either masters or slaves. One socket is equipped with 2 Kbytes of user-accessible memory that is expandable to 8 Kbytes. The other socket may house an additional 64 Kbytes. Users may take advantage of the 8044's features to off-load control and polling functions from the base-board unit.

iRCB 44/10 Bitibus Controller Multimodule. The remote controller board is an

Bitbus Backplane Configurations

Although the Bitbus interconnect is designed as a simple two-wire microcontroller interconnect, it can also be distributed over a backplane. The iRCB 44/10 Remote Controller Board uses a single-wide, 220 mm-deep, Eurocard format and DIN connectors as interface to power, other controllers, and I/O. Table 5 defines the pin-out of the 64-pin DIN connector which facilitates board insertion and maintenance; all I/O and bus connections are on the same connector. The connections are compatible with the standard Intel parallel port adopted by many other vendors. The power pins are compatible with standard Eurocard designations except for the ±12 V provided for the possible use of iSBX modules mounted on Bitbus controller boards.

Since the power and Bitbus connections occupy only a small number (14) of the backplane pins, many custom functions can be implemented on iRCB-type modules. Each module can include a controller and dedicated I/O circuitry designed for a particular application. The iDCM Controller manages all the Bitbus interface and provides the on-chip 8051 controller for local control.

Table 5. Eurocard Connector Pin-Out

DIN PIN #	PIN & SOCKET PIN #	FUNCTION	DIN PIN #	PIN & SOCKET PIN #	FUNCTION
1c		GND	1a		GND
2c		+5V	2a		+5V
3c		DATA*	3a		DATA
4c		DLCK*/RTS*	4a		DLCK/RTS
5c		RGND	5a	1	EXTINT
6c	2	GND	6a	3	PB7
7c	4	GND	7a	5	PB6
8c	6	GND	8a	7	PB5
9c	8	GND	9a	9	PB4
10c	10	GND	10a	11	PB3
11c	12	GND	11a	13	PB2
12c	14	GND	12a	15	PB1
13c	16	GND	13a	17	PB0
14c	18	GND	14a	19	PC3
15c	20	GND	15a	21	PC2
16c	22	GND	16a	23	PC1
17c	24	GND	17a	25	PC0
18c	26	GND	18a	27	PC4
19c	28	GND	19a	29	PC5
20c	30	GND	20a	31	PC6
21c	32	GND	21a	33	PC7
22c	34	GND	22a	35	PA7
23c	36	GND	23a	37	PA6
24c	38	GND	24a	39	PA5
25c	40	GND	25a	41	PA4
26c	42	GND	26a	43	PA3
27c	44	GND	27a	45	PA2
28c	46	GND	28a	47	PA1
29c	48	GND	29a	49	PA0
30c		−12V	30a		+12V
31c		+5V	31a		+5V
32c		GND	32a		GND

8044-based single-wide Eurocard form-factor board providing the standard Bitbus interface, memory expansion sockets, and clock-support circuitry found on the iSBX 344 Module. It also provides an expansion connector, and 24 lines of bit-programmable I/O. Connection is made by either a standard 10-pin connector or Eurocard 64-pin DIN connector. The iRCB 44/10 form-factor was selected to allow multiple concentrations of controllers.

DESIGNING A FLEXIBLE BITBUS ROBOT

Board and chip level modules can simplify many of the control problems inherent in robot architectures. High-speed central processors are necessary to manipulate positional coordinates and direct individual motor controllers to proper attitudes. Figure 2 shows the Bitbus approach to distributing the control while providing for future expansion and performance enhancements. In this example, the Multibus-based robot controller contains the iSBC 286/10 single board computer, an iSBC 012CX memory expansion board, an iSBC 186/03 single board computer, and two iSBX 344 Bitbus expansion modules. Each board performs a particular system function. The robot drive electronics are housed in a separate Eurocard housing mounted within the robot base. Bitbus connections link the robot controller to the robot, teaching pendant, and work-cell controller. An RS-232 interface is provided to support communication with existing display and control equipment.

Robot Controller. The iAPX 286/287-based computer board provides high-speed computational power to control overall robot motion. Simple high-level commands can be sent over the iSBX connector without regard to their eventual destination because no special software is needed to drive the robot link. The Bitbus controller will automatically send the command to the appropriate control node, ensure proper transmission, and continue polling the slave (interleaved with other commands) until an adequate response is relayed back to the base-board processor. If the computer board uses a multitasking operating system, message traffic can be maintained while the processor is calculating new position information and interacting with the RS-232 link and other processors.

Robot Drive Electronics. A collection of iRCB-style boards in the base of the robot provides servomotor control and sensory feedback to the robot controller. The custom servomotor drive card provides maximum flexibility for each axial motor. Each axial motor control card contains an iDCM Controller that maintains the Bitbus link to the master while performing all the required loop-control calculations. The card also contains inputs for individual limit sensors to maintain desired safety margins. The board is also capable of driving up to 24 auxilliary connections in end-effectors and other peripherals.

The number of degrees of freedom may be increased by adding another axial control card. The Bitbus interface to the robot controller makes it possible to enhance,

Bitbus Robot Example

The Bitbus microcontroller interconnect is well suited for a number of different robot applications. Figure 2 shows a typical robot workstation that includes a machine tool, two robots, a conveyer belt, and a central work-cell controller. The hierarchy of devices shown reflects the recent factory automation trend of connecting more machines to central accounting and control systems. One standard interface (labelled A) at the face-plate of each robot lets users select end-effectors from a variety of sources while maintaining a common control interface to the robot controller. The other standard interface (labelled B) ensures a coordinated work-cell by providing a way to connect robots, conveyers, etc. to the same work-cell controller with a simple and standard control interface.

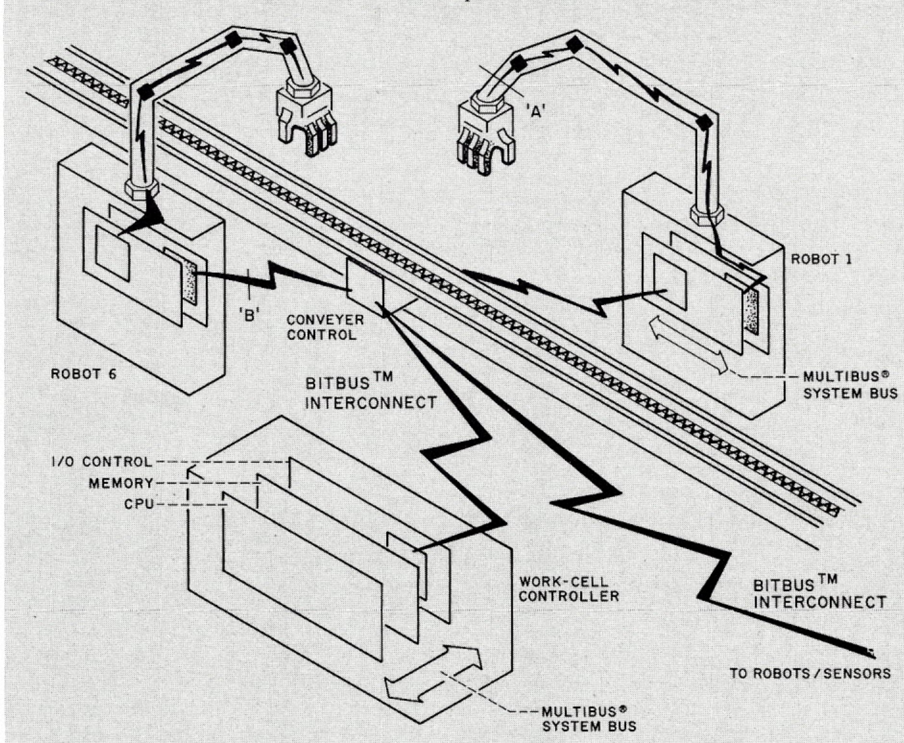


Figure 2. The Bitbus microcontroller interconnect is well suited for a number of different robot applications. Typical robot workstations include a machine tool, two robots, a conveyer belt, and a central work-cell controller. One standard interface (labelled A) at the face-plate of each robot lets users select end-effectors from a variety of sources while maintaining a common control interface to the robot controller. The other standard interface (labelled B) ensures a coordinated work-cell by providing a way to connect robots, conveyers, etc. to the same work-cell controller with a simple and standard control interface.

change, and substitute different robots without having to change hardware or software in the master controller.

CONCLUSION

The Bitbus microcontroller interconnect provides a method of connecting controllers in distributed control applications. By means of standard interfaces and specification of new and useful hardware and software interfaces, the Bitbus interconnect can link together many intelligent parts of industrial work-cells, distributed motor and device control, data acquisition, and distributed process control systems. Looking for a standard interconnect, Westinghouse, Unimation, Yasakawa Electric, Mitsubishi Electric, and other well-known industrial control vendors have already turned to the Bitbus as a possible means to remove the final obstacle preventing proper synchronization of high-performance distributed control systems. Using a standard interconnect allows previously isolated controllers to interact with other parts of a distributed control system—even when those parts are from many different vendors.

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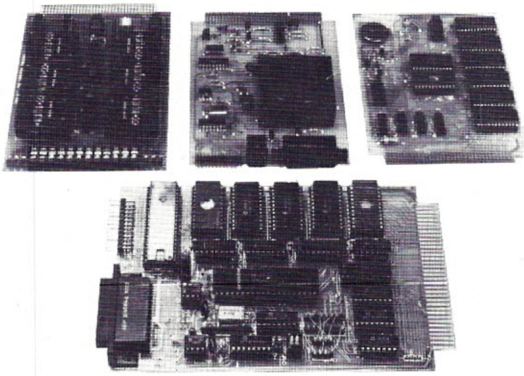

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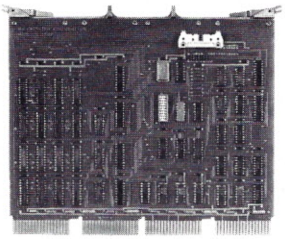

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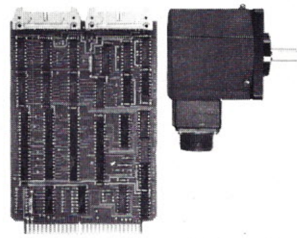

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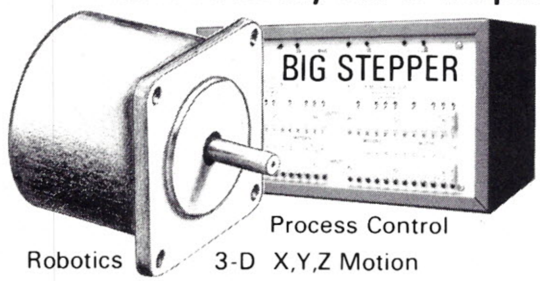

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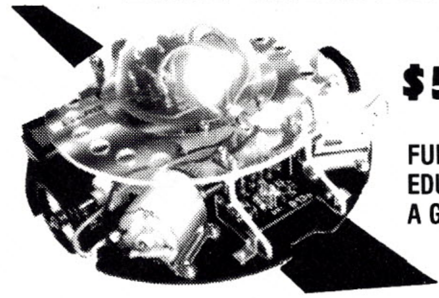

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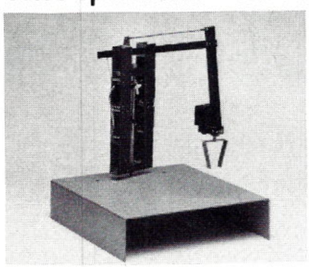

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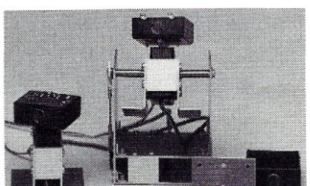

VISION 0 KIT $40; 2 for $70
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- Uses switched mode drivers, which regulate current through coils of the motor, and yield increased torque and a higher maximum step rate
- The motor supply voltage may be up to 46 volts
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- Full, half-step, and wave drive, plus an inhibit mode (drive power removed from the motor entirely) are selectable via the parallel port

The HS-2 controller card is available in both single and dual motor control versions. The single version is upgradeable to the dual version.

HS-2 Single Controller/Driver	**$ 99.00**
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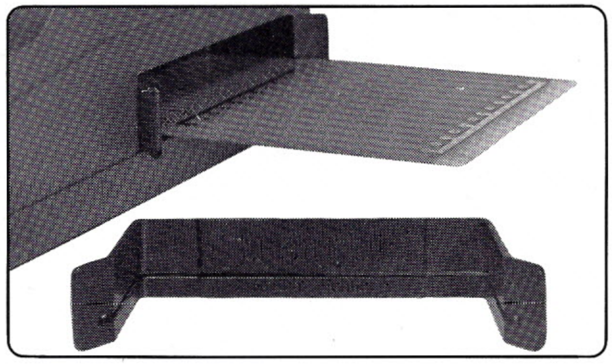
Circle 31

6809 SYSTEM DEVELOPMENT



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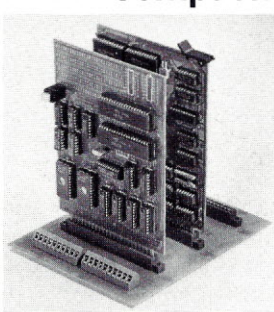

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- Optional 2K RAM
- Optional 2K EPROM
- Onboard Prototyping Space (with Holes & Solder Pads)
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Circle 34 Circle 17

Editorial

Continued from page 4

allow proud owners to take immediate control of their robots without having to learn a lot of complex program commands.

Conversely, the built-in Logo provides advanced program developers with a base for constructing pattern matchers, natural language programs, and problem solvers. From programming novice to advanced AI researcher, Logo provides a common thread for all levels of program development.

Logo is one of the most powerful programming languages ever to receive widespread acceptance. Let's not leave it just for our children and the turtles.

FUTURE ARTICLES

Part 2 of Charles Balmer's article on constructing a foundry will appear in the July issue of *Robotics Age*.

As always, we at *Robotics Age* like to hear from authors and potential authors with article ideas. If you are experimenting with some unusual systems or applications, give us a call and tell us about your discoveries. Some of our near-term plans for future issue themes include the use of robots in an educational environment, how to provide your robot with a sense of its environment through the use of low-cost data acquisition, a look at what is available in stepper motors and stepper motor controllers, vision systems and algorithms, real-time operating systems, and novel forms of locomotion including flight! If you have any ideas about what you would like to see in future issues of *Robotics Age*, give us a call, we're always happy to hear from you. [Ray Cote, editor]

Classified Advertising

MasterForth

MasterForth from MicroMotion meets all provisions of the new Forth-83 International Standard. MasterForth is a complete professional programming language and includes a built-in macroassembler with local labels, a screen editor, and a string handling package. The input and output streams are fully redirectable and make full use of the Apple DOS 3.3 file system. Floating point mathematics and high-resolution graphics options are available.

The package includes *Forth Tools*, a technical reference manual, and a complete listing of the MasterForth nucleus. *Forth Tools* provides an in-depth view of input and output from reading the input stream to writing a mailing list program. Numerous examples are provided.

MasterForth retails for $100 to $160 depending on options. For more information, contact: MicroMotion, 12077 Wilshire Blvd. #506, Los Angeles, CA 90025, telephone (213) 821-4340.

Circle 51

Expert-Ease

Expert-Ease is a software product which brings qualities of "expert" human intelligence to the microcomputer. It enables the user to construct expert systems without any knowledge of programming. The program, which operates on the IBM PC and certain IBM-compatible machines, claims to be the first practical microcomputer application of artificial intelligence.

Examples are presented to Expert-Ease as a list of attributes which the user considers to be relevant to the problem. The final entry for each example is the decision class. From these examples, Expert-Ease derives a classification rule in the form of a decision tree. Whenever a new example is found which refutes the current rule, Expert-Ease can be asked to restructure the rule so as to accommodate the new case.

The software is based on artificial intelligence research by Professor Donald Michie and J. Ross Quinlan of the University of Edinburgh. For more information, contact the the distributor: Jeffrey Perrone & Associates. Inc. 3685 17th St., San Francisco, CA 94114, telephone (415) 431-9562.

Circle 52

Driver Motor Cards

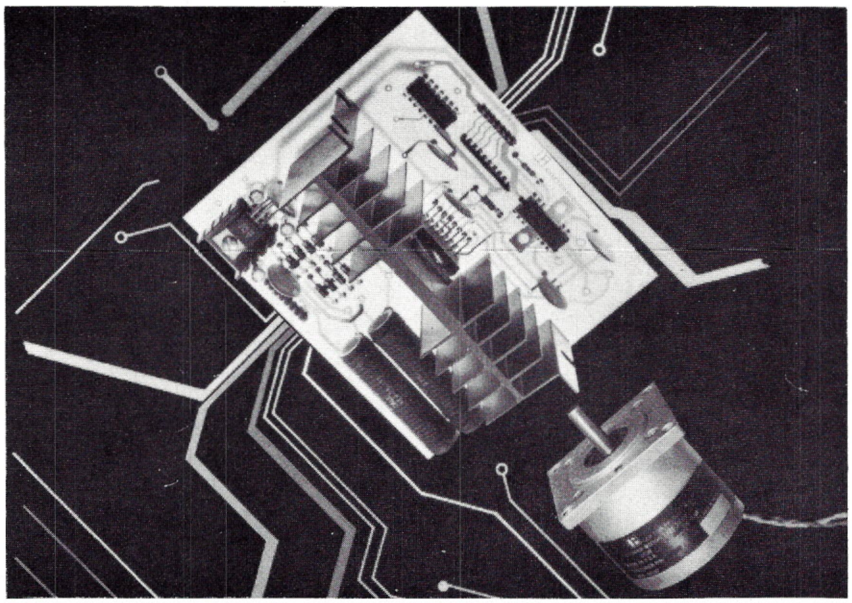
Two new stepper motor cards from Clifton Precision are suitable for prototyping, testing, and troubleshooting equipment designed with stepper motors. The driver cards allow engineers to fine-tune their prototype designs before their final stepper logic is built and incorporated into the equipment or system.

Model LR-BP-20-35 is a bipolar driver card used for basic driver applications. The card uses a 35 V input and has a 2 A per phase output. The board can accommodate series resistors to increase torque at higher step rates. Model PW-BP-50-45 is a high-performance driver card that offers pulse-width modulated control for maximum torque and accuracy required by high-performance applications. It uses a 45 V power supply and has an output of 5 A per phase. Series resistors are not required.

Both stepper motor driver cards are TTL-microprocessor compatible and have full- and half-step capability. Inputs for direction, clock, inhibit, and reset are provided.

For additional information, contact: Jim Chandler, Clifton Precision, PO Box 160, Murphy, NC 28906, telephone (704) 837-5115.

Circle 53



LSI-11 Robot Control

Digitax is a LSI-11-compatible package of building blocks which allows fast and reliable design of numerical control systems for multiaxis machines (industrial robots, etc.). Its main features are: performance, safety, flexibility, ease of maintenance, and programming.

Hardware included for each axis includes: a Q-Bus dual board with 6809 microprocessor and axis I/O control; a connection board with isolation, autotest, and manual control; a power drive for DC motors (50 V at 6A).

Software is provided on the LSI-11 for direct interface with high-level languages (FORTRAN, Pascal, and robot control languages). Real-time axis control is implemented efficiently on the 6809. For special axis control applications, a macroassembler and a real-time debugger are available to tailor the 6809 programs, using the host LSI-11 as a development system.

For more information, contact: Influx, Chemin des Clos, Z.I.R.S.T., 38240 Meylan, FRANCE, telephone (76) 41 02 81. Telex: 980 674. The United States representative is: F. M. Services, Inc., 405 N. Wabash Ave., Suite 3903, Chicago, IL 60611, telephone (312) 644-9515.

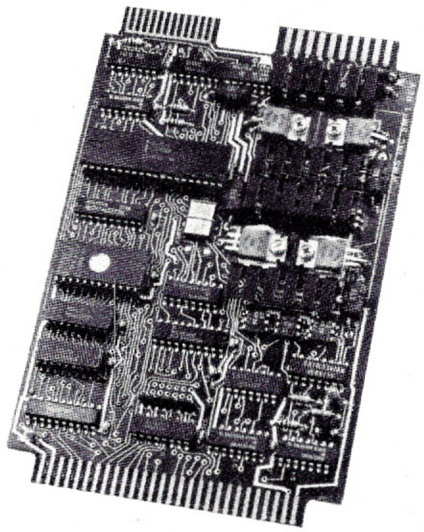
Circle 54

New Products

Smart Steps

The SM2 intelligent stepper motor controller includes onboard interrupt-driver software to allow multitasking operations. Other features include serial port chaining of several cards, enhanced ramp controls, and constant velocity commands. The onboard microprocessor has the ability to perform over 50 different preprogrammed commands. The board contains optically isolated motor-driven circuitry capable of driving four phase motors at over 2.5 A per phase.

Commands may be sent to the SM2 over either an RS-232 serial connection or through the STD Bus interface. Commands may be sent or received at any time, even while moving. The onboard software supports full, half, or user-defined step sequences; absolute or relative position modes; up to 65,536 steps per move command; and speeds of over 13,000 steps per second or as slow as 5 steps per minute.



Motor command programs may be stored onboard in nonvolatile memory.

For more information, contact: Advanced Micro Systems, Inc., 9 Executive Drive, Hudson, NH 03051, telephone (603) 882-1447.

Circle 55

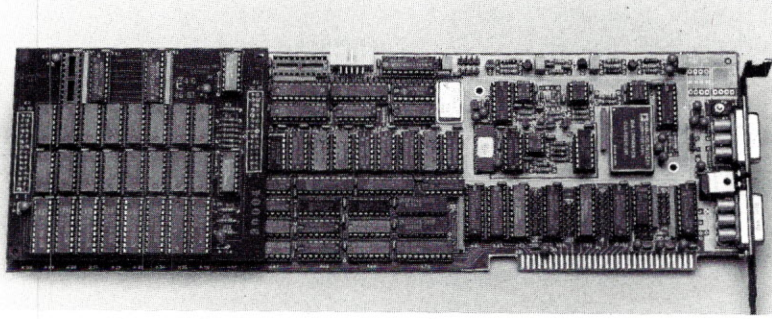
PCVISION Frame Grabber

The PCVISION™ Frame Grabber is a real-time video image acquisition and display module for the IBM PC and PC XT. The system includes a hardware module that plugs directly into an expansion slot in the IBM Personal Computer, comprehensive software driver routines, full documentation, and all required interconnecting cables.

The Frame Grabber converts a standard (RS-170) analog video signal from a camera to digital data at a 10M Hz rate, and stores the resulting six-bit pixel data in an onboard 512 by 512 frame memory. The system's architecture enables it to simultaneously acquire and display 30 frames per second. Programmable look-up tables on the output signal allow any arbitrary transformation of pixel intensity prior to display on an external monitor.

Each location in the onboard frame memory is eight bits deep and stores six bits of digital data (one of 64 gray scale intensities), with the remaining bits enabling two planes of graphic overlays. These graphic overlay planes can be used for generating and positioning text or graphics without disturbing the stored video data.

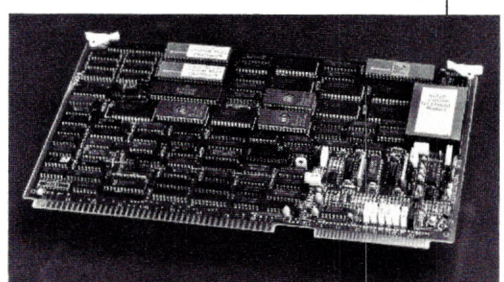
The complete PCVISION Frame Grabber costs $2995. For additional information, contact: Imaging Technology, Inc., 600 West Cummings Park, Woburn, MA 01801, telephone (617) 938-8444. Circle 56



Single-Board Voice Processing

A new hardware design offers Votan's full range of voice input/output technologies on a single, low-cost board. Voice recognition, speech compression, and complete telephone interfacing facilities are incorporated on a single VSP1000 Voice Processor board. The VSP1000 board, featuring Votan's newest continuous speech recognition technology, allows an individual to speak to the computer in a normal conversational flow. In addition, a "word spotting" capability enables the system to pick out target words from a stream of normal conversation. Speaker-independent recognition, which recognizes anyone's voice speaking a limited vocabulary, is also offered as an option.

Votan's speech compression on the VSP1000 provides human-sounding voice output capabilities for operator prompting and feedback by the machine. Based on a different technological approach than speech synthesis devices, Votan's speech compression produces a robotic sound yet maintains low bit rates for reduced storage and data transmission costs.

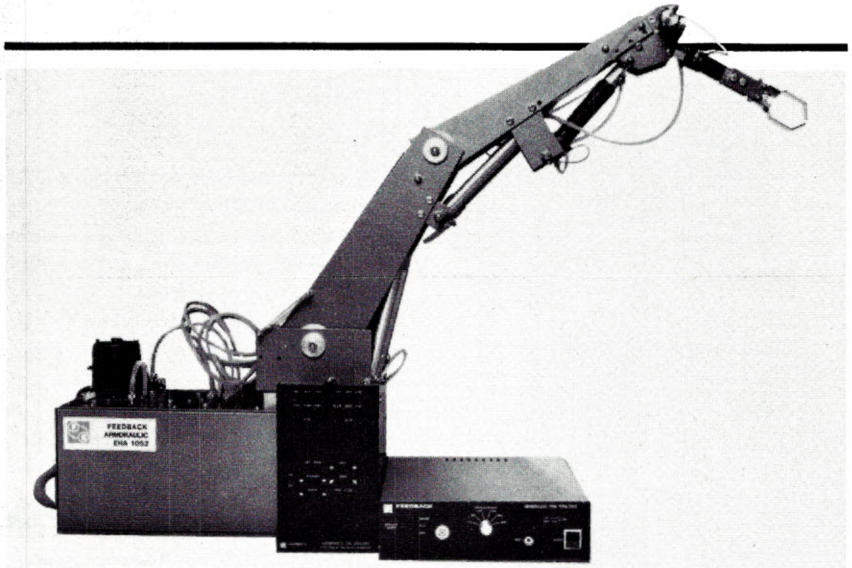


The VSP1000 contains all hardware required to service a voice channel under the control of a general-purpose system processor. By making use of the memory and processing power of the system processor, Votan was able to reduce the hardware requirements on their voice processor board for significant cost reduction. The system processor may be any single-board computer (8- or 16-bit) which is compatible with the IEEE-796 standard (Multibus). Single quantity price for the VSP1000 is $2,500.

For more information, contact: Votan, 4487 Technology Drive, Fremont, CA 94538, telephone (415) 490-7600.

Circle 57

New Products



Second Generation Hydraulic Teaching Robot

Feedback, Inc., has announced the availability of the Armdraulic MkII EHA 1052, a microprocessor-controlled hydraulic teaching robot particularly well suited for instruction on the university, vocational-technical school, industrial, and military levels. The second generation Armdraulic features expanded memory, enhanced hydraulics, and additional control features superior to its predecessor.

Controlled by a resident 6802 microprocessor, the robot's five axis revolute arm with two-fingered gripper can be programmed by either remote teaching pendant or optional external computer, via built-in RS-232C interface or eight-bit parallel port. The robot can store eight program sequences in its nonvolatile memory, each consisting of up to 64 preprogrammed arm positions. The closed loop system provides continuous position feedback from all axes including gripper, thus allowing maximum grip control.

According to Feedback, the 1052 uses double-acting hydraulic cylinders, which provide greater power for wrist raising and arm and wrist rotation. The robot's two-speed system automatically switches from normal to low speed as the arm approaches programmed pre-set coordinates, thus enabling more precise positioning. The Armdraulic 1052 robot has a maximum payload of six pounds fully retracted and three pounds at full extension.

For complete information, contact: Feedback, Inc., 620 Springfield Ave., Berkeley Heights, NJ 07922, telephone (201) 464-5181. Circle 58

Pertinent Books Reviewed

The 1984 edition of the Synapse book catalog functions as a central source for the latest, selected, high-quality books on robotics, automation, artificial intelligence, CAD/CAM/CAE, computer technology, biomedical engineering, instrumentation, telecommunications, and simulation. The illustrated catalog serves as a detailed, bibliographic resource providing accessibility to titles from over 30 publishers. The books included have been reviewed by a professional staff and represent the best of varying theoretical viewpoints at different technical levels.

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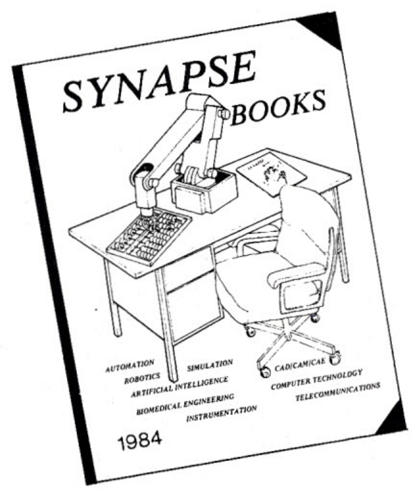

Circle 59

MS-DOS Speech Input System

Circle 60

Oto-I* is a speech recognition system for IBM PC and IBM PC-compatible computers using the MS-DOS operating system. The system consists of a single circuit board which plugs into any hardware expansion slot. A proprietary firmware/software combination provides a transparent interface with the applications program, allowing voice input to be used interactively with a keypad or other data entry device.

The Oto-I* speech recognition system provides better than 98 percent word recognition accuracy. A 128-word vocabulary can be stored onboard and expanded to 512 words or short phrases. The Oto-I* provides syntax control for up to 32 syntax subgroups. The hardware also controls automatic gain compensation and background noise level filtering.

Oto-I* is transparent to PC-DOS (MS-DOS), allowing users to easily place all existing software under voice control without writing additional software. The speech recognition package also contains VoiceKey,* a menu-driven program which guides the operator through the simple process of training the computer to recognize a vocabulary. SpeechIn* is a menu-driven program filled with instructional games and exercises which help the operator successfully substitute voice commands for keyboard control. OtoFile* is a vocabulary builder and controller which turns the Oto-I* speech recognition system into an unlimited vocabulary sytem. OtoFile* allows the operator to build an unlimited number of 128-word groups and to access them through syntax or keyword branching.

The Oto-I* speech recognition system is available for $795 from Lynn E. Taylor, MicroPhonics Technology Corporation, PO Box 7411, Federal Way, Washington 98003.

: CONTROL ! ;

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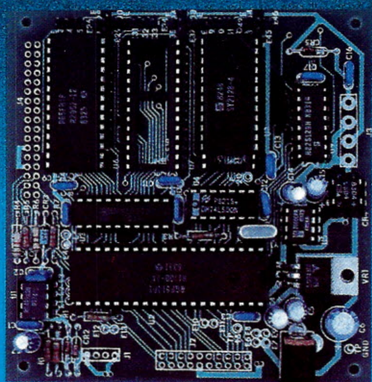

Our board, the NMIX-0111, the "100 Squared," surrounds the R65F11 with innovative circuitry that allows the chip to be a complete FORTH development system. All that is needed to do program development in FORTH is a CRT terminal or microcomputer that speaks RS232 (seven data, one start, two stop bits).

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RAM's	2016,2128,5517,6116,5564
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EEPROM's	2816A

The board can program in circuit:

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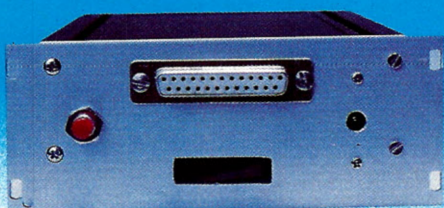
**requires additional VPP voltage supply.*



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All this plus the powerful R65F11 which features:

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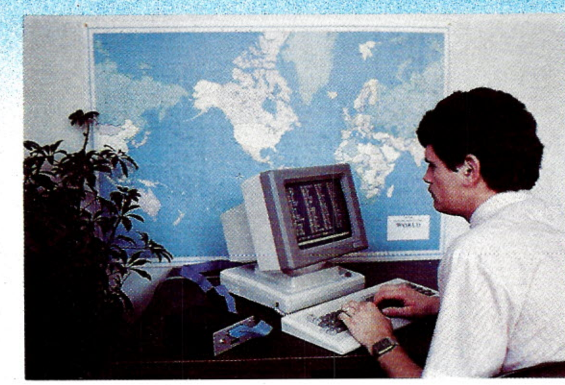

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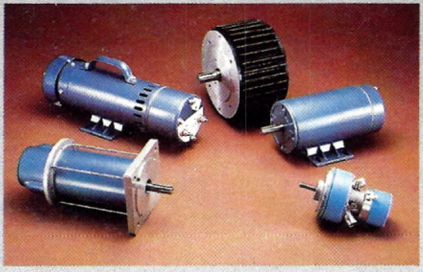
Honeywell Motor Products Division has a new name. We are now known as "Pacific Scientific Motor and Control Division." The acquisition took place earlier this year so our products will have a new label, but nothing else has changed.



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